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Assessment of Heat Stress for Outdoor Work Conditions in Saudi Arabia

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Abstract

Assessment of Heat Stress for Outdoor Work Condition in Saudi Arabia

by Jamal Alanazi

Outdoor workers have an increased risk of heat stress in Saudi Arabia since it is one of the hottest places in the Middle East. Recently, the government decided to limit outdoor work hours during the months of June, July, and August every year, and banned working under the direct sunlight from 12:00 to 03:00 p.m., although outdoor workers in the petroleum, natural gas, or emergency maintenance work industries are exempt from this prohibition. Traditionally, the efforts by safety and health professionals to mitigate work-related heat injury has been directed toward the assessment of environmental heat stress (e.g., wet-bulb globe temperature), rather than toward the associated physiological strain responses (e.g., heart rate and core temperatures). However, because a worker's physiological response to given heat stress is modified independently by individual factors of each worker (e.g., age, sex, chronic disease, others), it becomes challenging to protect workers on an individual basis from heat-related injury without assessing those physiological responses.

The primary objective of this study was to examine whether limiting work hours will reduce the risk of heat stress among outdoor workers or not. That can be achieved by (1) examining if the ban on three-month midday outdoor work needs to be extended to cover the period from June 1^{st} to September 30^{th} (2) examining if the midday break between 12:00 pm and 03:00 pm need to be extended by a few more hours.

A field study was carried out in Dammam City on Saudi Arabia's eastern coast where the humidity reaches 95% and temperature can reach 47°C (116.6°F) during summer months. The core temperature of 20 subjects matched for age, gender, and experience subjects was monitored while they performed their normal duties in the outdoor environment of Dammam City. The core temperature of these outdoor workers was measured using a novel non-invasive measurement method.

The obtained results showed that subjects were under the risk of heat stress over a large part of the workday and their body temperature exceeds the allowable core temperature (38.5°C; 101.3°F) which the ACGIH has proposed to protect workers from experiencing heat stress. The intensity of exposure was high from

(10:00-12:00 a.m.) that is not included in the midday break. A control group (non-policy) which did not experience the mid-day break showed essentially the same core body temperature as the experimental (policy) group.

Among chief findings was that complying with a midday break work ban (12:00–3:00 p.m.) was not effective in reducing heat stress risk under the conditions and limitations of the design. The policymakers should be informed that this particular policy is not helpful and does not significantly lower core body temperatures. Some policy modifications are suggested which might better impact core body temperatures under these extreme conditions.

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Chapter One: Introduction

1.1 Background

According to Occupational Safety and Health Administration (OSHA), workers exemplifying heat stress symptoms are often engaged in strenuous physical activities conducted either outdoors or in hot environments (OSHA, 2002). With the eminent global climate change, analysts expect that those working in outdoor environments will continue to be subjected to heat stress (Nichols et al., 2014). If the global warming hypothesis is correct about rising outdoor temperatures, the risks are likely to worsen in terms of severity, distribution and prevalence (Lucas et al., 2014; Schulte et al., 2016). These circumstances are expected to pose more challenges to the Saudi government and the working fraternity in the Middle East because outdoor work temperatures are even more severe than in North America. This is because the country is considered to have the hottest climate across the Middle East and the globe at large. For example, during the summer season, the intensity of the heat is constantly sustained till sunset. This kind of climate makes the country experience intense levels of temperatures everywhere.

According to Gubernot et al. 2015, the years between 2000 and 2010 saw over three hundred and fifty deaths recorded in the United States, with all the cases attributed to intense heat exposure. The Bureau of Statistics further notes that between 1999 to 2003, more than two hundred death cases were recorded along with fifteen thousand instances where the private sector allowed its workforce to work from home. All these instances were ascribed to effects associated with environmental heat.

The classification of environmental heat is based on a range of combined classifications comprising of heat illness (US Department of Labor, 1992). According to CDC, (Center of Disease Control and Prevention), a higher number of people affected by heat stress was incurred. For example, the organization states that on an annual basis, the United States recorded over 8015 deaths between the years 1979 to 2003. The urgency highlights that the number is quite shocking as it tends to surpass the aftermath of floods, hurricanes, lightning and tornadoes.

In terms of estimates, records indicate that each occurrence heat related illness stimulated a cost of $7500 (Bureau of Public Health Statistics, 2009). This is on top of the average wage loss of $150 per day due to time away from the job which equates to one hundred million dollars within the aforementioned five year period, or an alternative annual average of 20 million dollars (US Census Bureau, 2010). The amounts are only associated with acute illness and not fatal cases. The death workers in heat environments are the best examples to demonstrate heat related illness significance. The deaths have most of the occasions come along with high costs both ethical wise and economic wise. Most significantly, the CDC adds that intense temperatures of over 29.4°C (84.9°F), increases the probability of occupational injuries (CDC, 2006).

In environments where occupational heat is prevalent, certain aspects are expected. For example, a range of protective clothing, high physical work needs, and environmental humidity and heat. Employees exposed to such kind of conditions often convey physiological responses attributed to the heat stress. The response vary from increased body temperature, high heat rate, and intense sweating. Collectively, the responses are perceived as physiological heat strain. The heat stress severity is dependent on one's efficacy in thermoregulatory mechanism and the heat stress magnitude (Havenith& Van Middendorp, 1990).

Heat strain is perceived as the physiological response of the body to heat stress (ACGIH, 2001). Medical analysts advocate that heat strain has a variety of effects on one's body. For instance, it stimulates an increase in body temperature, fatigue or fainting, and frequent thirst. In order to sustain normalcy in body functionality, a core temperature of 37°C (98.6°F) must be maintained. Our bodies are capable of sustaining this balance by undertaking physiological adjustments that give room for efficient exchange of heat between the ambient environment and the body (Katić et al., 2016).

Under normal heat stress situations, the heat strain physiological responses facilitate the body to be able to regulate its temperature, and this helps a worker's body in sustaining a steady thermal state. Consistent exposure to intense high temperatures results in the body's thermoregulatory defenses being overtaxed. This gradually leads to a projecting body temperature, sweat loss, and heat rate. In other words, constant exposure to such strain increases the risk of heat illness. The illness vary in severity from acute cardiovascular to intensified damage on the central nervous system.

Core heat illnesses comprise of heat syncope, heat cramps, heat stroke and heat exhaustion. Heat cramps often take place in skeletal muscles perceived as voluntary. The muscles are located in the arms, legs, and abdomen. The cramps are considered muscle spasms that are involuntary that sometimes may also occur in specific exercised muscles. On the same note, heat syncope facilitates pooling of the blood into cutaneous vessels that are dilated and lower extremities. If these factors are left unchecked, they may result in cerebral and systemic hypotension and eventually, unconsciousness. Heat exhaustion can occur in an individual with normal or elevated core body temperature. Its symptoms include weak, rapid pulse, hypotension while in the upright position, headache, fatigue, nausea, and clammy, moist skin. Heatstroke is the most severe heat illness and is a true medical emergency. In the case of heatstroke, an uncontrolled rise in core body temperature occurs which often results in damage to the central nervous system and numerous vital organs.

The extreme complexities in estimating heat stress aspects has been key in ensuring lack of a conventional system. These aspects facilitate the transfer of heat between the environment and skin. (Pandolf and Moran, 2005) Alternatively, other factors such as those that define the metabolic heat unloading from skin to body also affect the process of heat transfer. Some of the key factors that operate within such heat transfer processes include air speed, air temperature, relative humidity, emissivity and temperature of the solids, skin temperature, pressure of the skin's water vapor, clothing and the skin's surface area. When it comes to metabolic heat unloading to the skin from the body, some of the key factors include metabolic heat generation, core temperature, skin temperature, blood circulation into essential organ, sweat production, sweat production, and hydration levels. It is worth noting that it has been unfruitful incorporating all the factors essential in moving heat to skin within a single heat stress index. (Potter et al., 2017).

However, despite all the unsuccessful attempts, the American Conference of Governmental Industrial Hygienist (ACGIH) recognizes WBGT (Wet Bulb Globe Temperature) as conventional standard in heat stress analysis. Other agencies running this recognition include the Occupational Safety and Health Administration (OSHA), the International Standards Organization (ISO) (ACGIH, 1993; ISO, 1989).

As much as the WBGT index is being accepted as the conventional standard, the index fails to provide reliable and consistent predictions and estimations for individual heat strain. Inherent (imitations of the index fail to account for unacclimatized, unfit workers; workers that are unhealthy or are taking medication that may interfere with their thermoregulatory system; healthy workers of different heat tolerance levels; subjective biases in an evaluator's determination of the metabolic (internal) heat production; the lack of a safe tolerance time and a time for recovery when the internal and external heat loads do not allow heat balance to be established; and different clothing than assumed in the empirical derivation of the index.

A wide range of measures is employed in protecting employees from heat-related illness. Analysts advise that employers need to pay attention to not only environmental parameters but also clothing and metabolic heat generation estimates. These factors are employed in quantifying heat stress levels and determining hygiene practices, administrative and engineering controls. Highlighting and working along these factors help prevent severe heat strain levels. As much as this, provisions a standard approach in estimating the average physiological strain level, the real heat strain level of an individual can markedly vary. Experts attribute this to inter personal factors such as chronic disease, sex, age, among others. The variance in individuals can result in under protection or over protection from heat strain effects. Some of the factors that create the variance in individuals result in poor productivity or a compromise in safety for workers with less tolerance to heat.

Common heat stress physiological responses include increased sweat rate, skin temperature, heart rate, and core temperature. One's response to heat stress is also dependent on the individual's personal factors. The factors include gender, fitness level, and acclimation state. Physiological adaptations are induced by one's acclimation to the heat which in turn helps reduce heat tolerance. General adaptations are sweat rate, high plasma levels, and reduced heart rate. Studies show that an individual's fitness also strongly contribute to heat stress response. This is because participating in aerobic training stimulate similar adaptations as acclimation. Scholars urge that there is a wide range of heat strain response in genders. The studies undertaken by the scholars portray the differences research that does not individual's based on matching criteria. It is evident that the differences tend to be minimal in the event that participants are matched and acclimated on aerobic capacity.

Precise evaluation examining whether an occupational environment may result in heat strain should incorporate defining workers' heat strain parameters. Physiological monitoring of the worker would allow a direct determination of the worker's health status. Vital temperature of the body is meant to portray a body's thermal state (Brengelmann, 1987). Therefore, its value is meant to mirror the effects of environmental heat loads, physical work demands, individual variables, and wearing protective clothing. Ideally, core temperature would be measured in the pulmonary artery; however, non-invasive surrogates must be substituted in workplace environments. An individual's core temperature is often measured at the esophagus, rectum, mouth, or external ear canal. It is essential that an accurate measure of the thermal state of the body also fit within the imitations found in occupational environments.

To acquire a quantifying mean in real time of each employee's heat strain level, physiological strain monitoring is critical. This is because it tends to provide protection on an individual basis against heat illnesses (NIOSH, 2018). Technology innovation has greatly led to the recent advancement in wearable physiological monitor. In addition, the innovation has strongly fueled the continuing extensive research in the systems utility. The increase in the wearables is continuing to be advocated for as they significantly help in monitoring one's physical activity. Based on recent reviews, the wearable technology has greatly helped in optimizing performance, tracking rehabilitation, and disease identification (Sawka and Friedl, 2018).

Statistics indicate that harsh conditions in most industries have occupational heat stress. Harsh conditions in this case refers to high humidity and temperature, poor air flow, and radiant heat sources. In addition, it is evident that the heat stress may also be fueled by the industries' requirements such as wearing protective clothing that are impermeable or insulated and heavy task that stimulate metabolic heat loads. In other terms, the wearing of heavy work equipment strongly contributes towards heat strain (Arbury et al., 2014). It is therefore obvious that undertaking arduous work in high temperature environments spurs gradual increase in cardiovascular strain, core temperature as well as fluid depletion. Severe exposure to heat stress conditions result in heat stroke or even death. Analysts note that intense heat strain can stimulate psychophysical strain such as fatigue and discomfort. Such may cause poor employee productivity and safety hence labor loss (Ioannou et al. 2018). The aforementioned psychophysical and physiological effects related to heat stress on an employee's performance showcase the eventual response to heat strain.

In understanding the heat stress process in human physiology, significant progress has been accomplished in an effort to make the public conceptualize more of the topic. As much as numerous strategies have been employed to mitigate injuries that are heat related in industries, exposure to heat stress is still a primary cause of mortality and morbidity. Some of the strategies being employed in the mitigation include employees self-monitoring and frequent assessment of heat stress (Arbury et al. 2014; Xiang et al. 2015). It is based on the reasons that recommendations have been made highlighting the significance of including programs for heat strain monitoring. The programs are meant to boost the process of identifying symptoms of severe heat strain or illnesses (NIOSH, 2018). The strategies can be well defined by examining the protection level offered to employees.

1. Self-Monitoring

It is common knowledge that in cases of heat strain or when heat illness symptoms are evident, employees tend to modify their behavior. For example, they may remove clothing, cut their productivity or request for more rest time (Mairiaux and Malchaire, 1985; Budd, 2001; Ioannou et al., 2018). Research finds that self-monitoring can become ineffective in the wake of productivity incentives (Mairiaux et al., 1983). Evidence shows that workers can still be exposed to heat stroke and heat strain despite the freedom to self-pacing (Cuddy and Ruby, 2011). In sum, scholars concur that self-monitoring is only key in offering low level protection with respect to an employee's health.

2. Heat-Stress Monitoring

Numerous industries are employing environmental parameters to effectively halt excess heat strain. Other parameters employed in the prevention include clothing and environmental parameters and predicted metabolic heat production rate. The parameters are vital as they are employed in identifying factors that fuel severe heat strain. Alternatively, the parameters help in mathematical modelling of heat stress levels likely to be incurred by an employee. The employee experience however is determined by thermal and anatomical body properties as well as the responses to facilitate heat loss (Richards and Fiala, 2004). In circumstances that are viewed to be dangerous, hygiene practices, such as fluid consumption, engineering, such as shade and ventilation, and administrative tools like working duties are prescribed to combat injuries related to heat. It is noteworthy that individual variability is extensive since heat stress is subject to modification by intra and inter - individual aspects. The factors tend to be beyond and within an employee’s control.

3. Heat-Strain Monitoring

To facilitate advanced protection, physiological heat strain indices are vital in helping to quantify the intensity of heat stress incurred by employee on a real time basis. This is undertaken while paying attention to inter and intra-individual aspects that often adjust heat strain independently. The strategy therefore tends to hinder under or over protection of employees from illnesses that are heat related. It achieves this by implementing strategies that increase. Productivity in workers that have high tolerance to heat. Physiological data can be employed in to alert management in ensuring adherence to safety limits. At the same time, they are critical in providing physiological feedback to employees. This helps employees to be able to monitor their working rate thus combating severe heat stress while optimizing productivity. In sum, physiological monitoring has been found to effective in improving protection level stimulated by self-monitoring (Buller et al. 2018).

In regulating fluid volume, blood pressure and body temperature regulation, occupational heat strain plays a key role. It achieves this by collaborating with numerous physiological adjustments. Despite the responses representing heat stress indices, it is challenging to quantify them in occupational environments. Even the current technological innovation does not help. While quantifying severe heat stress, certain physiological responses can be estimated. This helps in reinforcing the employees' health. As much as measuring changes in hydration or sweat loss in one's body can help in heat strain quantification, much attention is directed towards on indices. Often, the indices are defined by the recent wearable technology. This can be indirectly or directly. This kind of technology achieves the results by measuring indirectly the core temperature or determining them noninvasively.

A. Core Temperature

Heat strains most direct index is the incapability to regulate the vital temperature during work (Haldane, 1905). Severe increase in core temperature that is above 40°C (104°F), often results in organ failure and worse cases, death. It is worth noting however, that the condition can get severe in the event that medical care is delayed or neglected (Leon and Bouchama, 2015). It is based on this facts the ACGIH proposes that core temperatures must be within the limit of 38°C (100.4°F) and 38.5°C (101.3°F). The two limits represent extension of both acclimatized and unacclimatized. Further, the organization defines the most favorable rest/work ratios as well as the most effective intensity of work to sustain the ratio. In any occupational setting, it can be challenging to achieve core temperatures that are clinically relevant. In certain instances, the measurement technique's invasive nature can only spur discomfort but also be distracting. This is often the result when it is employed for an extended period of time. Below are techniques used in approximating a workplace's core temperature.

1. Gastrointestinal temperature, this kind of temperature is estimated using a telemetric pill. The method is effective in providing core temperature. It acquires this by examining the entire process of ingestion to passing. To create a conducive working temperature, the temperature acquired by the telemetric pill has to be shared (Ganio et al. 2009).

2. Oral temperature, this method is often employed in quantifying occupational heat stress in collaboration with the rate of heat while recovering. Experts adopt oral temperature to track the temperature of the rectum during work.

3. Tympanic and aural temperature, tympanic membrane along with aural temperature convey a clear picture of the temperature in the brain. They provide a more accurate core temperature index since for tympanic membrane for example, directly exchanges blood with the brain (Brinnel and Cabanac, 1989).

4. Temperature of the body surface, the skin acts as the medium between the external environment and inner body.

B. Heart Rate

Increase in heart rate not only sustains the delivery of oxygen and regulation of blood pressure but also it supports compensatory adjustments of cardiovascular. This helps regulate and monitor the core temperature (Sawka, 1988). The regulation is made because the heart rate increases occur in line with increases in both core temperature and metabolic demand (Haldane, 1905). To effectively assess one's heat strain, the rate of the heart needs to be averaged during recovery periods or work (Brouha, 1960). Alternatively, it can be averaged to estimate the core temperature. To measure the heart conveniently, portable, lightweight monitors can be used. The monitors are effective since they are equipped with transmitting devices that alert managers and workers in the event of severe heat strain. When examining heat stress using the rate of the heart, aspects that independently affect hearts rate have to be carefully considered. Below is an extensive analysis of heart rate recovery as well as core temperature estimation.

1. Average rate of the heart, in many occupations, workers exposed to high intensity work in sporadic periods. Working on such circumstances can cause one to increase their heart rate beyond the static upper limit. At the same time, working for

a long period can elicit the heart rate slightly under the upper threshold. The response of the heart rate represents a level of heat strain that escapes undetected. Therefore, analysts advise that temporary average heart rate is essential in helping estimate the safe thresholds of working (Bernard and Kenney, 1994). According to the ACGIH guidelines, the maximum heart rate should range at 180 beats.

2. Heart rate recovery, the projection in the rate of the heart beats is often followed by a gradual decline upon completion of the activity (Brouha, 1960). Certain argue that to effectively examine heat strain, heart rate recovery must be considered (Fuller and Smith, 1981).

Recently, heart rate can be used to predict core temperature. The Kalman Filter (Kalman, 1960) has been preferred as the most effective tool in measuring the core temperature by examining the heart rate's time dependent factors. The filter is proved to be a reliable tool as it is employed in econometrics and engineering to predict data trends. The tool is being adopted in field and laboratory experiments to examine working in hot temperatures (Buller et al., 2013).

The recent innovations in technology have spurred the increase in wearable monitors. That monitors provide portable and noninvasive techniques that help quantify numerous physiological responses aforementioned. The responses that can be estimated in occupations in order to quantify severe heat stress and hence safeguarding employees from occupational heat. (Notley et al., 2018)

1.2 Purpose of the Study

A few years ago, Saudi Arabia began shifting its focus on the importance of occupational health and safety. Pone of the first policy adjustments of that change was that the central government banned working under the direct sunlight from 12 noon to 3 p.m. between June 15 and September 15 every year. (Note: outdoor workers in the petroleum, natural gas, or emergency maintenance work industries are exempt from this prohibition) This decision was taken based on the daily peak temperature. Regulation is irregularly enforced and temperatures can still be extremely high during non-restricted hours. Moreover, occupational surveillance data for heat-related illness in Saudi Arabia are lacking and no comprehensive study has been done to assess the heat stress among outdoor workers.

Unfortunately, both the Saudi General Authority of Statistic, and the General Organization for Social Insurance (GOSI) which is a Saudi Arabian government agency concerned with social insurance in the country, do not have statistics about workers exposed to heat stress. Due to this failing to collect data regarding heat stress exposure, and with taking in account the climate change and more extreme weather and the lack of similar studies in the Saudi context, it will be better to provide policy makers with empirical assessments on the risk of heat exposure, to identify problems and to suggest interventions in a preventive manner.

Policies based on data and empirical observations seem a better route for occupational safety and health to protect thousands of workers rather than taking actions based on good intentions alone. Preliminary data for this area are needed in order to take the decisions based on evidence; this dissertation is a first-attempt to do this.

1.3 Research Objectives

The objectives of this dissertation are:

1. to quantify the effects of heat stress using an accepted technology under more severe conditions than have been assessed in North America.

2. to inform occupational safety policy-makers whether the restriction time protects employees who work under the direct sunlight or not;

3. to heighten awareness of worker susceptibility to heat stress and to increase awareness in occupational health and government arenas.

Chapter Two: Literature Review

2.1 What is the Heat Stress?

When one's body fails to regulate heat balance, heat stress appears. Heat balance is modulated by many different mechanisms within the human environment system, known as homeostasis. In hot environments, the breakdown in homeostasis causes hyperthermia. Core body temperature can project to severe levels in the event that homeostasis is lost. For example, it becomes lethal if the core temperature rises by 3°C (37.4°F). (Simon, 1993). Continuous work induces higher temperature within the human body. Therefore, in order to maintain homeostasis blood flow transfers this heat to the skin. At the skin, heat transfer is dependent on the environment. There are four different methods of heat transport at the exterior of a human body: radiation, convection, conduction, and evaporation (Simon, 1993; Gaughan et al., 2009). As heat projects in the external environment to the body, the main technique of removing excess heat is through evaporation. This method regulates seventy five percent of the lost heat (Koppe et al., 2004). Future weather predictions show that when conditions become too humid, the human body can no longer use sweat to remove heat, and cannot survive (Sherwood and Huber, 2010).

2.2 Influence on Economies and Labor Productivity

The natural reaction of any individual when working in a hot environment is to seek ways to regulate the core temperature. Often, this involves reducing physical activity. Some of the effective ways employed to reduce the activities is by cutting the hours of working. This cuts the time within which one is exposed to the hot temperatures. Slow economic growth is well associated with weather fluctuations. Heat waves on the other hand also stimulate the reduction in productivity. Labor productivity in today's world tends to weaken by 2% when it gets hotter than 25°C (77°F), (Dell et al., and 2014). Models of heat stress convey the idea that often the level of production may reduce by between 11 to 27% in the next 50 years. This is more likely to be incurred in hot regions such as the Caribbean and Asia (Kjellstrom et al., 2009). Asia conventionally, it is expected that in 30 years' time productivity will cut by 20% (Dunne et al., 2013). The reduction in productivity is being witnessed most of the time among individuals that often undertake the heavy work outdoors. This is because the nature of their work tends to expose them to intense solar radiation that combines with their internal body heat (Kovats and Hajat, 2008). Scholars argue that this scenarios highlight the continuing inequality since outdoor works are often undertake by poor people (Kjellstrom et al., 2009).

2.3 Cost Associated with Heat Injuries and Heat Stress.

According to the Bureau of Labor Statistics, heart-related illnesses are estimated to cost $7500 per occurrence. The institution further notes that an additional $150 per day is lost in wage equating to over one hundred million dollars within five years. The list is only attributed to acute illnesses and excludes fatal instances (US Census Bureau, 2010). The economic cost associated with the deaths of employees draws a clear picture of the impact of heat-related illnesses. The case is made worse by the ethical impact of the illness. Studies by the CDC show that workers working in ambient temperatures above 29.4°C (84.9°F) tend to be more susceptible to occupational injuries (CDC, 2006).

According to the ILO statistics, they estimate that more than 80 million workers on full time jobs will be influenced by heat strain and productivity reduction. The Organization argues that most of those to be affected will originate from South East Asia and West Africa. The overall cost of the losses is expected to hit 2.4 trillion dollars annually. Based on research conducted under the Warmer Planet report, the average temperature of the globe is likely to project by 1.5°C (34.7°F).

2.4 Biological Responses to Heat Stress

In the event of heat stress, the human body tends to adapt by hosting several external and internal systems. Biological studies show that this level of adaptation helps the body sustain homeostasis. When one's body is overpowered by the internal heat generation, hyperthermia occurs (Simon, 1993). Thermal control is monitored and regulated by the hypothalamus, which is biologically responsible for peripheral or autonomic nervous systems.

A range of organs in the body is often stimulated to respond accordingly in the event of an abnormality in the core body temperature. The hypothalamus is a trigger to this reaction. It achieves this by introducing chemical compounds to the body hence inducing the desired reactions (Simon, 1993). In other words, the hypothalamus is primarily responsible for thermoregulation. For instance, if there is an increase in internal temperature, vasodilation, and an increase in heart rate are initiated by the hypothalamus. Vasodilation is the process by which blood vessels dilate (Simon, 1993; Yokota et al., 2008).

To regulate the internal temperature further, heat is transported to the skin where it is lost through sweating by evaporation. The human skin is composed of several glands that collectively generate fatty secretions like sebum and sweat. The purpose of sebum is to emulsify and prevent the dripping of sweat off the skin. This characteristic bolsters the skin's capability to achieve maximum evaporation. (Lupi, 2008). It is worth noting that if the external environment contains a level of moisture that may reduce the impact of evaporation, the hypothalamus will become ineffective in heat regulation.

Thermoregulation becomes even more challenging in the wake of extreme moisture conditions and temperature. These kinds of challenges have prod scientists to study further into ways that can help the body improve its adaptation to heat stress. Acclimatization is noted as an effective approach in boosting the body's adaptation to various environmental conditions. An individual's state of acclimatization directly influences oxygen volume, respiratory rate, and oxygen volume (Pandolf and Kamon, 1974). Additionally, one's age and physical fitness also factor in the ability to withstand heat stress. A physically fit body tends to generate approximately three liters of sweat per hour. Studies show that tissues have a lesser thermal conductivity than other tissues (Gardner et al., 1996). The environment is a key factor in the regulation of the blood flow rates and pressure. Koppe et al., (2004) finds that the vascular system of the body tends to respond distinctively to strenuous exposures. The density of blood vessels increases with an increase in internal body temperature. In parallel, their capacity reduces during low temperatures. The lungs also respond distinctively to environmental changes. For example, air sacs in the lungs change in density in the event of altitude change.

2.5 Metrics of Heat Strain

The various ways a body responds to heat stress are described as indications of heat strain. The most commonly measured heat strain indicators are body temperature and heart rate.

2.5.1 Body Temperature

2.5.1.1 Surrogate and Core Temperature

The best gauge for heat stress is one's internal temperature (Bishop, 1997). It indicates the body's overall heat capacity. It is through the aspects of internal body temperature that an index can be created to help predict a population's percentage that is likely to experience heat strain in severe temperatures (Sawka et al., 2001). According to WHO (WHO, 1969), one's internal body temperature must not surpass 38°C (100.4°F). However, it is acceptable for the core temperature to be at 39°C (102.2°F). NIOSH (2018) documents that deep temperatures of the body that, exceed 38°C (100.4°F), are unfavorable for conducive working in an industry. According to ACGIH (2006), heat strain evaluation is necessary in the event the core temperature hits 38.5°C (101.3°F).

The actual core body temperature can be read by subjects swallowing thermometers encapsulated in pills. This strategy is effective in constantly monitoring temperature as readings are continuously transmitted via radiofrequency. However, scientists insist that this is not only invasive in nature but also expensive. Moreover, studies show that their usage causes complications. For example, one may experience certain abnormalities if the pill was to break open after being swallowed.

When one is exposed to severe heat, the adjustments he or she incurs in terms of temperature in the rectal and hypothalamus is of equal magnitude. In other terms, the rectal temperature (T_{re}) reflects the increase in heat and core temperature (Astrand et al., 2003). Rectal temperature has long been applied in laboratory experiments hence it is employed as the standard. All core temperature measures are defined by efficiency in estimating rectal temperature (Bernard & Kenney, 1994).

2.5.1.2 Oral Temperature (T_{oral})

Strydom et al., (1965) recorded a difference between T_{oral} and T_{re} of O.65°C (33.1°F). Mairiaux et al., (1983) recorded 0.33°C (32.5°F) difference. Currently, the consensus points to T_{oral} as the most reliable indicator of heat stress cumulative effects (Logan & Bernard, 1999; Moran & Mendal, 2002; Stephenson et al., 1974). T_{oral} under 38°C (100.4°F) is accepted since T_{re} is set by OELs at 38.5°C (101.3°F). This is recorded or used in well monitored cases of acclimated workers (ACGIH, 2001; NIOSH, 2018)

Disposable and electronic thermometers are designed to have adequate reliability and accuracy especially those that measure T_{oral}. In order to improve on accuracy, one is advised not to smoke or take any hot or cold drink 15 minutes to the test. During the test, the mouth must be closed to avoid any instance of evaporation (Beaird et al., 1996; Moran & Mendal, 2002; Terndrup et al., 1989).

2.5.1.3 Temperature of the Ear Canal (T_{ear})

The above literature notes that T_{ear} is a stable core temperature measure (Ishii et al., 1993). Observing accuracy while measuring the T_{ear} helps acquire the brain's temperature. Some scholars note that it might be more vital than T_{re} (Knochel, 1996). Belding & Kamon (1973) and Belding discovered that the readings of T_{ear} were consistently read between 0.5°C (32.9°F) and 0.6°C (33.1°F) under T_{re}. The effects of the environment on the head are crucial in T_{ear} being able to map T_{re}. Sites, (1981) documented the environmental impact on T_{ear}. The effects were found to be severe in the event of inappropriate insulation. Muir et al (2001) adopted an effectively insulated ear thermistor that helped increase the accuracy in estimating T_{ear} and T_{re}. The accurately measure T_{ear}, temperature sensor, thermistor, is placed next to the eardrum, then covered with ear plug foam to protect it from environmental conditions. To reduce the margin of error in the core temperature, vapor barrier coveralls are used. They help to create a microenvironment well excluded from the ambient environment (Muir et al., 2001).

2.5.2 Heart Rate

In light of environmental and metabolic stress, the human body tends to respond by increasing the rate of heartbeats. Biologists use heartbeat as a heartbeat indicator (Salvendy, 2012). The heartbeat is said to increase when one engages in high workloads within an acceptable ambient temperature as well as when carrying out sedimentary in a high-temperature environment (Bernard and Kenny, 1994). Within the period of workload or high-temperature exposure, there is no lag in upon increase in a heartbeat (Fuller and Smith, 1981). However, based on aspects such as diseases like thyroid and anemia and personal fitness, the response time and baseline of the heart rate tend to vary. Scholars add that medications such as bronchodilators and antidepressants also influence the variance (Bernard and Kenny, 1994). According to NIOSH, the heart rate must be noted a minute after the subject completes tasks. This institution acknowledges that collecting data while following this procedure increases the chances of gathering accurate recovery heart rate (HRrec).

Subsequent studies suggest that to get a clear picture of the body's ability to recover and adapt to heat stress, data on three heart rates must be collected upon completion (Belding and Kamon, 1973). In line with industrial hygiene monitoring, the central goal is to research with minimal interruption to the daily schedule of workers. NIOSH underlines a range of upper limit recommendations. For instance, it suggests that upon a resting period of three minutes and the HR is above, 90 bpm, the subject must be put under observation. The institution further recommends a limit of one minute upon recording 110 bpm (NIOSH, 2018). Scholars conventionally concur with the effectiveness of this limit including a study by Bernard and Kenny, (1994). According to ACGIH TLV, extreme heat strain often occurs as a result of continuous HR when subjects work in environments that prompt bpm above 180. To accurately mitigate such threats, the ACGIH advises subjects to be constantly monitored. Excessive heat strain effects can also be experienced when HRrec exceeds 120 bpm after one minute of working (ACGIH, 2006).

The new innovated monitors have been specially designed to accurately estimate and record HR. bearing in mind the intensity of industrial wok, HR related transient increases are likely to occur beyond the threshold. Such threshold convey positive false alarm making them physiologically inefficient. Alternatively, having an elevated threshold can HRs that are maintained. This may result in a long physiological strain. With a data logging function, HRs can be used as a demand indicator throughout the course of working. According to Minard et al. (1971) workers who record a greater than 120 bpm HRs encountered a significant reduction in aerobic capacity. It is worth noting therefore that MTA of HR tends to avoid static threshold problems (Bernard & Kenney, 1994).

2.6 Heat Related Illness

When one's body becomes incapable of sustaining its normal functioning within the narrow range, effects of the abnormality tend to range from potential death to minor consequences. The sections below seeks to explicate the effects of continuous exposure to high temperatures. In other terms, it covers temperatures that negatively influence the manner in which adapts to changes. Table (2.1) shows signs of Heat Related Illness.

2.6.1 Heat Stroke

This medical situation is caused by malfunctioning of the heat balance mechanism. In most instances, one starts to experience a dramatic increase in core temperature and excessive sweating (ACGIH, 2001). The rectal temperature on the other hand often projects to 40.5°C (104.9°F) (Bernard et al., 1991). As soon as the core temperature approaches its peak, the hypothalamic temperature regulators, get destroyed. This makes the body continue to increase its core temperature since the heat loss mechanism has been dismantled. The extreme heat exposure stimulates symptoms such as lack of sweating. However, this may not be the case in all instances. At this level, the major threat is always death. Previous experiments and experiences have shown that attempts to halt the sporadic increase in temperature in order to prevent death have been unsuccessful. In the event that death does not occur, one tends to be incapacitated to a significant extent. The heat often causes irreversible damage to internal organs (Belding and Hatch, 1955).

2.6.2 Heat Exhaustion

Heat loss mechanism can be overtaxed resulting in heat exhaustion (Belding and Hatch, 1955). Often, it occurs due to the depletion of electrolytes and body fluids. However, if one is properly diagnosed, the severity of the heat stroke can be neutralized (OSHA, 2002). Common symptoms that showcase the presence of heat exhaustion include headache, paling skin, profuse sweating, thirst, vertigo, and extreme tingling sensations (ACGIH, 1993). Extreme elevation of core temperatures may result in one fainting (Belding and Hatch, 1955). The blood volume may also be affected in the event that one loss of water exceeds one percent. The loss tends to affect plasma thus causing inability in the cardiovascular system when responding to thermoregulation and work demand. The symptoms and effects become more profound with an increase in dehydration. Resting and rehydration will result in recovery, however, this happens in mild cases. It may become necessary to use intravenous fluid in worse cases.

2.6.3 Heat Cramps

When an occupation calls for laborious work, heat cramps are always evident. However, heat cramp effects are mild compared to heat exhaustion and heat stroke. The cramps become evident in muscles mostly used in the work activity. Often, they are painful with much pain felt in the abdomen. This is mostly due to the excess sweating which causes high loss of salts (ACGIH, 1993). To neutralize the pain, one is advised to take a lot of water, rest and the lost electrolytes are replaced (OSHA, 2002).

2.6.4 Heat Syncope

During heat stress, heat syncope becomes a condition that causes one to faint and become unconscious. This condition tends to occur to unacclimatized individuals. Usually, it occurs due to low blood pressure which is often triggered by sudden posture changes. Alternatively, heat syncope may become evident in the evident due to peripheral vasodilation, a situation that allows extreme blood pooling. To combat this condition, occupational activities need to incorporate extreme movement. Those suffering from the condition must be placed to rest in cool areas (ISO, 1989).

2.6.5 Heat Rash

Heat rash is a skin irritation caused by excessive sweating during 4 hot, humid weather. Common names for heat rash include prickly heat or Miliaria. Figure 2.1 shows the classification of body temperature.

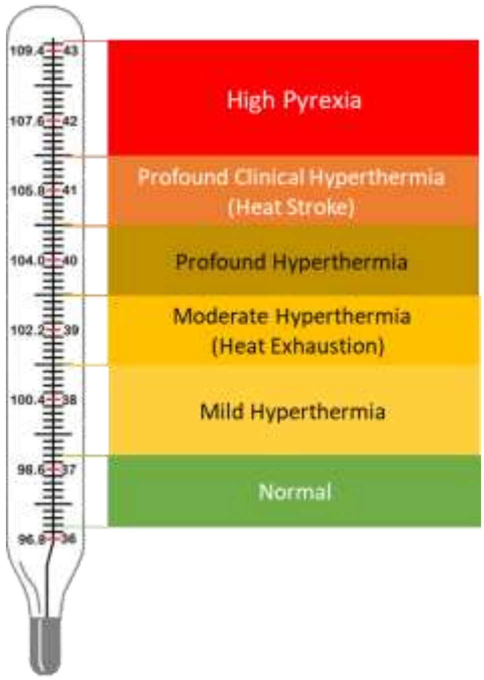

Figure 2.1 classification of body temperature

Table 2.1 Signs of Heat Related Illness

Illness	Signs
Heat Stroke	High Body Temperature (39.4°C; 102.9°F Or Higher),Hot, Red, Dry, Or Damp Skin, Losing Consciousness (Passing Out), Blood In Urine Or Stool , Low Blood Pressure, Dizziness & Fainting, Decreased Sweating, Shortness of Breath, Rapid Strong Pulse, Slurred Speech, Hallucinations, No Sweating, Convulsions, Throbbing, Confusion, Headache, Vertigo, Nausea, Chills
Heat Exhaustion	Pale, Cold, Clammy Skin , Fast, Shallow Breathing, Cold Or Clammy Skin, Fast, Weak Pulse, Heavy Sweating, Muscle Cramps, Headache, Weakness, Confusion, Dizziness, Vomiting, Fainting, Fatigue, Nausea, Thirst
Heat Cramps	Muscle Pain, Muscle Tightness, Muscle Spasms, Pain In Abdomen, Arms, or Legs
Heat Syncope	Sudden dizziness, Feeling faint or fainting, Pale and sweaty skin but is generally moist and cool, The pulse may be weakened, Rapid heart rate, Body temperature is normal
Heat Rash	Looks like red cluster of pimples or small blisters, Usually appears on the neck, upper chest, groin, under the breasts, and in elbow creases

2.7 Heat Transfer

The body loses heat through:

1. **Evaporation.** Through sweating, the body is able to regulate the core temperature. Breathing or respiration helps regulate the temperature when the body gets above 37°C (98.6°F). In windy and dry climatic conditions loss of heat through respiration and evaporation increases.
2. **Radiation.** In air temperatures lower than 20°C (68°F), the body generated heat is lost to the surrounding.
3. **Conduction.** In air temperatures below 20°C (68°F), heat is given off. About 3% of the body heat is lost through conduction. It is worth noting that water stimulates more heat to be lost than air. Therefore, when placed in cold water, heat can be lost rapidly.
4. **Convection.** This is where water or air flows by the skin allowing them to absorb heat from the body through the skin. Through convection, the body loses between 10% to 15%.

2.8 Thermal Comfort

Fanger (1970) explains that comfort can be satisfactory only when skin temperature, core temperature, and sweat rate are set within the subjective comfort limit. Some claim that the relevant parameters can be explained in an approach that is measurable like core temp between 36.5°C (97.7°F) and 37.5°C (99.5°F) while the body is allowed to excrete heat through sweating. The intra body temperature, during rest in comfort, maintains its level at 36.8°C (98.2°F) and when walking it projects to 37.4°C (99.3°F) and hits 37.9°C (100.2°F) when jogging (Chen, 2019).

Simultaneously, the skin temperature in sedentary activities needs to be maintained at 33-34°C (91.4-93.2°F) or 31-34°C (87.8-93.2°F) (Auliciems & Szokolay, 2007) and decreases with increasing physical activity. Such information reveals that while the internal temperature rises with increasing level of physical activity, the skin temperature decreases, owing to the mechanism of sweating, which facilitates heat loss. Heat dissipation is a physiological adaptation towards uncomfortable rates of thermal conditions, to bring the body into a state of thermal equilibrium (Szokolay, 2014).

Outdoor workers experience much higher variations than those indoors, owing to the solar and terrestrial radiation fluxes (Matzarakis et al., 2010; Ghasemi et al., 2015). Taking these fluxes into account in outdoor spaces is "decisive because they are extremely variable spatially as well as temporarily" (Toudert and Mayer, 2005). Figure 2.1 shows the various parameters influencing heat exchange of the body with its surrounding environment in outdoor settings. Some of these are induced by meteorological parameters, whereas others are related to bodily characteristics, and can be expressed by Equation 1 (Matzarakis & Amelung, 2008):

$$\Delta S = (M - W) \pm C \pm R - E \text{ .... (Equation 2.1)}$$

Where;

ΔS = change in body heat content

(M-W) = total metabolism - external work performed

C = convective heat exchange

R = radiative heat exchange

E = evaporative heat loss

Metabolic heat production measurement, wind velocity, air temperature, air water vapor pressure, and mean radiant temperature are required to solve the equation. (Belding, 1970)

Convection (C):

$$C = 7.0\, V_a^{0.6}(t_a - \bar{t}_{sk}) \text{ .... (Equation 2.2)}$$

Where;

C = convective heat exchange, $kcal \cdot h^{-1}$

V_a = air velocity in meters per second ($m \cdot sec^{-1}$)

t_a = ambient air temperature °C

$\bar{t}_{sk}$ = mean weighted skin temperature, usually assumed to be 35°C (95°F)

Radiation (R)

$$R = 6.6\,(\bar{t}_w - \bar{t}_{sk}) \text{ .... (Equation 2.3)}$$

Where;

R = radiant heat exchange, $kcal \cdot h^{-1}$ or $W \cdot m^{-2}$

$\bar{t}_w$ = mean radiant temperature of the solid surrounding surface, °C

$\bar{t}_{sk}$ = mean weighted skin temperature

Evaporation (E)

$$E = 14\, V_a^{0.6}(P_{sk} - P_a) \text{ .... (Equation 2.4)}$$

Where;

E = Evaporative heat loss, $kcal \cdot h^{-1}$

V_a = air speed, $m \cdot s^{-1}$

P_a = water vapor pressure of ambient air, mmHg

P_{sk} = vapor pressure of water on skin, assumed to be 42 mmHg (5.6 kP_a) at a 35°C (95°F) skin temperature

Conduction (K)

$$h_k = KA\,(T_1 - T_2)/l \text{ .... (Equation 2.5)}$$

Where;

h_k = Heat exchange via conduction

K = Thermal "conductivity" determined by the physical properties of the objects

A = Area for conduction of heat, m^2

l = Distance between points at T_1 and T_2 for the conduction for heat, m

T_1 = Temperature of the warmer object, °C

T_2 = Temperature of the cooler object, °C

Outdoor workers are subjected to the influence of other parameters; although at varying degrees (Höppe & Seidl, 1991). For this, the ASHRAE describes thermal comfort as "the condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation" (Mukhopadhyay, 2019). Some researchers argue this definition is vague, because other factors play an influential role when studying outdoor thermal comfort (e.g. Nikolopoulou et al., 2001; Alznafer, 2014). Hence, the ASHRAE identifies six primary aspects that influence thermal comfort and classifies them into two categories:

A. Environmental Factors:

1. Mean radiant temperature

2. Relative humidity

3. Ambient air temperature

4. Wind velocity

B. Behavioral Factors:

5. Activity 'metabolic rate

6. Clothing resistance

Ambient Air Temperature (T_a) °C

This is the temperature of the normal air. It is often perceived as Dry bulb temperature. This type of temp is used in defining the nature of heat flow between the environment and one's body. Conventionally, temperature plays a key role in enhancing comfort in any environment. When the temperature of the ambient air is significantly high, the aforementioned process becomes very difficult. When to feel uncomfortably cold when the surrounding temperatures fall. The fall causes the body's heat loss to become rapid hence causing the cold feeling (Boduch and Fincher, 2009).

Relative Humidity (RH)%

The ratio between the real amount of water in the atmosphere and the maximum capacity the atmosphere can sustain within the same temperature. Relative humidity works long with wet bulbs and dry bulb temperatures to stimulate comfort or discomfort. However temperature is still vital in creating thermal comfort phenomenological sense. Elevated relative humidity levels can tend to function contrary to cooling effects of evaporation such as sweating. Increasing the probability of overheating. In the event that relative surpasses the accepted maximum threshold, discomfort is stimulated. This may be due to the creation of high moisture content (Sunkpal et al., 2018).

Wind Velocity (v) m/s

Also known as air movement, it is perceived as the average air speed that the body faces. This is affected by one's location and time. Often, physiological cooling effect is created by wind velocity since it increases convection, accelerates skin evaporation and changes the clothing and skin surface (Szokolay, 2014). To effectively sustain thermal comfort, accelerating the velocity of air is the most effective strategy (Wang et al., 2012).

Mean Radiant Temperature (T_{mrt})

It is understood as the average spatial temperature of an individual's surrounding surfaces. It is also commonly referred to as Back Globe temperature (Szokolay, 2014). Globe temperature can be effectively used to predict T_{mrt}, which is difficult to directly measure. The equation below gives a clear illustration in the absence of air movement, the Tmrt = T_g (Szokolay, 2014).

$$T_{mrt} = \left[\left(T_g + 273.15\right)^4 + \left(\frac{1.1\times10^8 v^{0.6}}{\varepsilon D^{0.4}}\right) \times T_g - T_a\right]^{0.25} - 273.15 \text{ .... (Equation 2.6)}$$

In that;

Air Temperature (°C) = T_a

Black Globe Temperature (°C) = T_g

Wind Velocity (m/s) = v

Globe Diameter (mm) = D

Globe Emissivity = ε

T_{mrt} effect on outdoor workers with light clothing in hot climates can be twice as significant as the T_a, "which gives rise to the environmental temperature" (Szokolay, 2014). Thus, the Tmrt "can be more than 30 K higher than T_a in exposed locations and even up to 5 K in shaded parts, due to the diffuse and reflected solar radiation components" (Toudert and Mayer, 2005).

Employees Clothing (Clo)

This is mostly perceived as the major insulation or thermal resistance between the environment and the human body. The insulation it offers is quantified based on Clo values. (1 Clo = 0.155 m2/W insulation value).

Metabolic Rate of Employees (M)

This is the excretion by oxidation process in terms of energy. The process tends to rely on one's muscular activity. The rate of metabolism tends to vary in line with an activity's intensity. An individual's body weight is directly proportional to metabolic rate, sex, body surface, environment thermal and amount of clothing (Auliciems & Szokolay, 2007).

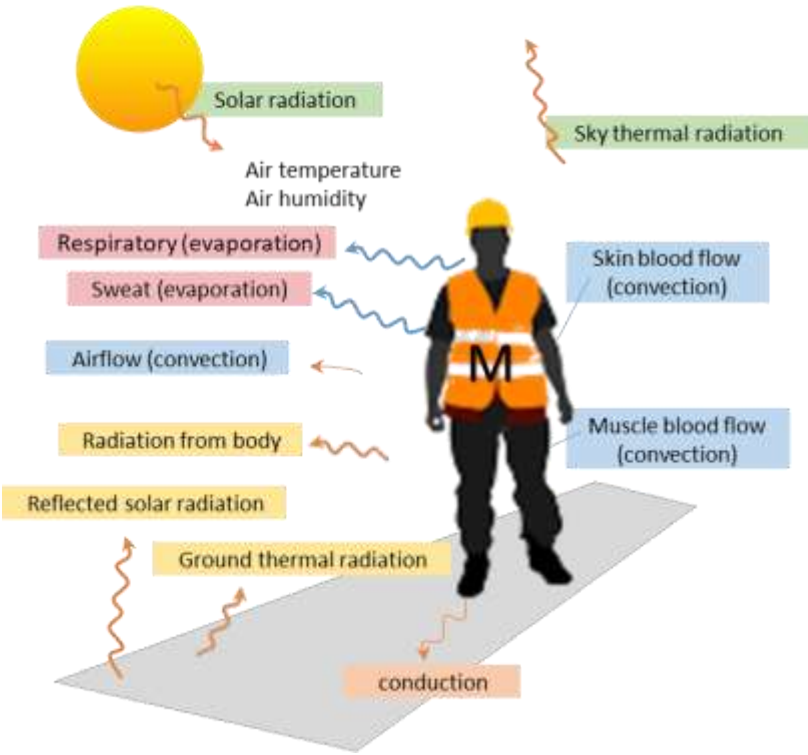

Figure 2.2 Factors affecting thermal balance of outdoor workers

2.9 Heat Stress Indices

An index in heat stress represents a basic parameter impact on the thermal environment to an extent that its value is dependent on an individual's heat strain (Parsons, 2003). Haldane (1905) assessed these factors then concluded the use of wet bulb temperature. It is based on this principle that research in climate change still prioritizes the single parameter. An extensive human climate indices register with 162 values is continuing to be used across the globe, in table 2.2 about forty indices are listed. (De Freitas et al., 2015; Havenith and Fiala 2011; Oliveira et al., 2019) The collective environmental variable effect used to be a huge hindrance to the index purpose. As time went by, clothing and metabolic rate effects were taken into consideration. Scholars note that research is still on to use a single value to examine heat stress (Belding, 1970; Gagge and Nishi, 1976).

Upon recent studies and research, it has been concluded that simple things are easily applied in the field (Havenith and Fiala, 2011). Research contexts however seem to be more interested in adopting complex models. Noteworthy, not all indices meet the requirements. On certain occasions they tend to exemplify conflicting demands in validity, simplicity, and reliability. As much as there is an intense debate about the use of the indices, the most effective choice relies on the conditions, one's experience and the prowess to run comparison between studies.

Indices under heat strain can be categorized into rational indices (rely on calculations e.g. SW_{req}, TWL), Empirical indices (depend on subjective and objective strain), and direct indices (incorporate measuring environmental parameters directly) (Epstein & Moran, 2006; Coco et al., 2016). In occupations, it is very challenging to incorporate the indices of the first two groups. This is because they tend to engage with a range of variables that call for invasive measurements. The friendlier group is the third group. Scholars claim they are more applicable since they focus more on environmental variables.

Indices based on equations have been described as the most comprehensive. They tend to combine all variables both behavioral and environmental. Some of the parameters are portrayed as constants since it is impractical to record all the elements. The HSI is a perfect example as it relies on the constant skin temperature of 35°C (95°F) (Belding, 1970).

A lot of emphasis seems to be directed to the accuracy of an index while neglecting practicability. Real scenarios show that workplaces differ contrary to how they are conveyed in laboratories. In parallel, other vital factors that appear to be confirming range from the type of clothing acclimatization degree and gender. Using a complete and reliable index to assess heat stress in workplaces is an important aim of every researcher. However, it is quite impossible to successfully run a comparison of heat indices with valid techniques. Clearly, it is worth reiterating that workers exposed to high temperature conditions showcase physiological responses attributed to the heat stress. The response vary from increased body temperature, high heat rate, and intense sweating. The heat stress severity is dependent on one's efficacy in thermoregulatory mechanism and the heat stress magnitude

Based on ISO, WBGT, Wet Bulb Globe Temperature, is supposed to be employed to ease the process of heat strain screening. PHS, predicted Heat strain, should be used to assess both heat strain and stress. In sum, ISO formulates the fundamentals of how to conduct heat stress management. In many developed countries, public health officials employ the WBGT to investigate cases of heat stroke like in the United States and, Japan (Tanaka 2007; Martinez et al., 2011). Much conclusion has been made that WBGT lacks consistency in high temperature environs, locals tend to disregard 30°C (86°F) as an extreme hot temperature case (D'Ambrosio Alfano et al. 2014).

Table 2.2 Some of Heat Stress Indices (Source; Epstein & Moran, 2006)

Year	Index	Author(s)
1905	Wet-bulb temperature (T_w)	Haldane
1916	Katathermometer	Hill et al.
1923	Effective temperature (ET)	Houghton & Yaglou
1929	Equivalent temperature (Teq)	Dufton
1932	Corrected effective temperature (CET)	Vernon & Warner
1937	Operative temperature (OpT)	Winslow et al.
1945	Thermal acceptance ratio (TAR)	Ionides et al.
1945	Index of physiological effect (Ep)	Robinson et al.
1946	Corrected effective temperature (CET)	Bedford
1947	Predicted 4-h sweat rate (P4SR)	McArdel et al.
1948	Resultant temperature (RT)	Missenard et al.
1950	Craig index (I)	Craig
1955	Heat stress index (HIS)	Belding & Hatch
1957	Wet-bulg globe temperature (WBGT)	Yaglou & Minard
1957	Oxford index (WD)	Lind & Hellon
1957	Discomfort index (DI)	Thom
1958	Thermal strain index (TSI)	Lee & Henschel
1959	Discomfort index (DI)	Tennenbaum et al.
1960	Cumulative discomfort index (CumDI)	Tennenbaum et al.
1960	Index of physiological strain (Is)	Hall & Polte
1962	Index of thermal stress (ITS)	Givoni
1966	Heat strain index (corrected) (HSI)	McKarns & Brief
1966	Prediction of heart rate (HR)	Fuller & Brouha
1967	Effective radiant field (ERF)	Gagge et al.
1970	Predicted mean vote (PMV)	Fanger
	Threshold limit value (TLV)	
1970	Prescriptive zone	Lind
1971	New effective temperature (ET*)	Gagge et al.
1971	Wet globe temperature (WGT)	Botsford
1971	Humid operative temperature	Nishi & Gagge

Year	Index	Author(s)
1972	Predicted body core temperature	Givoni & Goldman
1972	Skin wettedness	Kerslake
1973	Standard effective temperature (SET)	Gagge et al.
1973	Predicted heart rate	Givoni & Goldman
1978	Skin wettedness	Gonzales et al.
1979	Fighter index of thermal stress (FITS)	Nunneley & Stribley
1981	Effective heat strain index (EHSI)	Kamon & Ryan
1982	Predicted sweat loss (msw)	Shapiro et al.
1985	Required sweating (SW_{req})	ISO 7933
1986	Predicted mean vote (modified) (PMV)	Gagge et al.
1996	Cumulative heat strain index (CHSI)	Frank et al.
1998	Physiological strain index (PSI)	Moran et al.
1999	Modified discomfort index (MDI)	Moran et al.
2001	Environmental stress index (ESI)	Moran et al.
2005	Wet-bulb dry temperature (WBDT)	Wallace et al.
2005	Relative humidity dry temperature (RHDT)	Wallace et al.

2.9.1 Hot Humid Climate Heat Stress Indices

A wide range of indices developed by scholars have been adopted in the hot humid climate. They include Temperature Humidity Index (THI), Wet Bulb Globe Temperature (WBGT), and Universal Thermal Climate Index (UTCI), Humidex, and Tropical Summer Index (TSI). It is however uncertain on which index is suitable and reliable.

1. Humidex

Humidex has been designed to operate in high humid and hot areas. It used to portray how people will feel when it gets hotter. It incorporates humidity and temperature into a single value. It however does not showcase wind velocity and solar radiation. This tool is widely employed in Canada which often avails a humidex calculator to boost interpretation of the data. Table 2.3 illustrates the thermal threshold for this index.

Table 2.3 Assessing Heat Stress Based on Humidex

Humidex (°C)	Degree of comfort and discomfort
Less than 29	Little Or No Discomfort
30 to 34	Noticeable Discomfort
35 to 39	Evident Discomfort
40 to 45	Intense Discomfort; Avoid Exertion
45 to 54	Dangerous Discomfort
Above 54	Heat Stroke Probable

2. WBGT (Wet Bulb Globe Temperature)

Conventionally, WBGT is perceived as quite reliant as a stress index. It is built with three distinct thermometers that are designed to various aspects of the environment. That is; a dry bulb (T_{db}), black globe (T_g), and wet bulb (T_{wb}) temperature. The US navy developed it to help study injuries related to the heat. It pay attention to humidity, temperature and radiant temperature. Table 2.4 illustrates the thermal threshold for this index.

Table 2.4 Assessing Heat Stress Based on WBGT

WBGT	**Thermal zones**
20-25	Caution
25-32	Extreme Caution
32-39	Danger
Above 40	Extreme Danger

3. TSI (Tropical Summer Index)

It was constructed by Sharma & Sharafat (1986), Indian scholars. It effectively functions in warm humid and hot dry conditions. Its effectiveness is more precise when the radiant flux is within a reasonable threshold. It pays attention to the primary variables of the environment. Table 2.5 illustrates the thermal threshold for this index.

Table 2.5 Assessing Heat Stress Based on TSI

TSI (°C)	**Thermal sensation**
19-25	Slightly cool
25-30	Comfortable
30-34	Slightly warm

$$TSI = \frac{1}{3}\,T_{wb} + \frac{3}{4}\,T_g - 2\,v^{0.5} \quad \text{.................(Equation 2.7)}$$

Where;

T_{wb} : Wet Bulb Temperature

T_g : Black Globe Temperature

v: wind velocity

4. THI (Temperature Humidity Index)

It concentrates on temperature and humidity. It works effectively when placed in a shaded area and safe from the wind. Created in 1959 by Thom. Initially, it was used to detect discomfort caused by heat stress. Currently, its use has been extended to assess cold stress conditions. Table 2.6 illustrates the thermal threshold for this index.

Table 2.6 Assessing Heat Stress Based on THI

THI (°C)	Thermal category
bellow −40	Hyperglacial
−39.9 to −20	Glacial
−19.9 to −10	Extremely cold
−9.9 to −1.8	Very cold
−1.7 to +12.9	Cold
+13 to +14.9	Cool
+15 to +19.9	Comfortable
+20 to +26.4	Hot
+26.5 to +29.9	Very hot
above +30	Torrid

$$THI = 0.8 \times T_{db} + RH \times (T_{db} - 14.4) + 46.4 \quad \text{.................(Equation 2.8)}$$

Where;

T_{db} = Dry Bulb Temperature in °C

RH = Relative Humidity expressed as a proportion

5. Universal Thermal Climate Index (UTCI)

Was created to give the public a feeling of the weather. It considers all the aspects of the environment of wind, temperature, humidity and radiation (Bröde et al., 2010) and the index is on the temperature scale (in degrees Celsius) (Richards and Havenith, 2007). UTCI will be calculated online. Table 2.7 illustrates the thermal threshold for this index.

Table 2.7 Assessing Heat Stress Based on UTCI

UTCI (°C)	Thermal category
bellow −40	Extreme cold stress
−40 to −27	Very strong cold stress
−27 to −13	Strong cold stress
−13 to 0	Moderate cold stress
0 to +9	Slight cold stress
+9 to +26	No thermal stress
+26 to +32	Moderate heat stress
+32 to +38	Strong heat stress
+38 to +46	Very strong heat stress
above +46	Extreme heat stress

2.10 Standards

2.10.1 OSHA and California OSHA

The primary objective of having occupational exposure limitations is to help define a heat stress level deemed excessive. Occupational exposure limits play an essential role in evaluating a working environment's vulnerability to heat illnesses. OSHA regulations on heat stress mitigation are inadequate at the federal level. OSHA's clause of General duty, employers are directed to construct their workplaces into environments that easily help combat heat hazards (Lind, 1963). This clause is conventional within federal governments to be specific on heat exposures. Scholars however note that OSHA failed to incorporate advisory committees when drafting the clause. Therefore, they attribute the ineffectiveness of the clause to the lack of expert advice and recommendations. This is well displayed in the OSHA Technical Manual (OTM). Notably, the recommendations listed in the Manual were drafted to mirror the ACGIH TLV guidelines. The 2010 promulgated regulation 3395 by California OSHA titled Heat Illness Prevention was revised to help address the risk emanating from occupational heat stress.

Upon examination of the OSHA guideline, experts conclude that it tends to focus extensively on workers in construction, transportation, agriculture, and oil and gas. However, only certain sections of the regulation cover all other industries. The guideline is also limited to addressing concerns of workers operating in outdoor environments and excludes those operating indoors. Therefore studies show that this level of exclusion has resulted in increased cases of heat illnesses. The major regulating factor used by OSHA is the two dry-bulb (Ta) ambient air temperatures. The factor leads to assumption that if temperatures hit the 29.4 °C (84.9°F) mark, specific procedures have to be followed. For example, employers must avail water and shade. If the temperature exceeds the 35 °C (95°F) level, the regulation dictates further actions be undertaken. For example, close monitoring and supervision (Cal/OSHA 2010). The need and importance of safeguarding employees from heat illnesses have been cemented by the recent safety procedures adopted by the military. In three states, the military is continuously implementing standards aimed at protecting employees both in indoor and outdoor environments from heat strain. The implementation of the standards active in states namely Washington, Minnesota, and California. In Minnesota, indoor guidelines are more active.

2.10.2 NIOSH RAL/REL & ACGIH TLV

The guidelines that seem to be most frequently used by industry are the NIOSH REL (Recommended Exposure Level) and RAL (Recommended Alert Level) and the ACGIH Threshold Limit Value (TLV). The guidelines offer more insight into how companies can adjust their exposure level and alert levels. Compared to regulatory standards, the latter is considered more protective and conservative to workers.

2.10.2.1 NIOSH Criteria for a Recommended Standard

NIOSH provided a detailed guideline in 2016 that extensively defines measures on occupational exposure to heat and hot environments. The guidelines comprise of the following elements:

A. Heat Stress Threshold

NIOSH advocates that employees should not be exposed to working environments characterized by environmental and metabolic heat exceeding the recommended alert limits or RELs. These apply to unacclimatized and acclimatized workers respectively. (Figure **2.3** and Figure **2.4**).

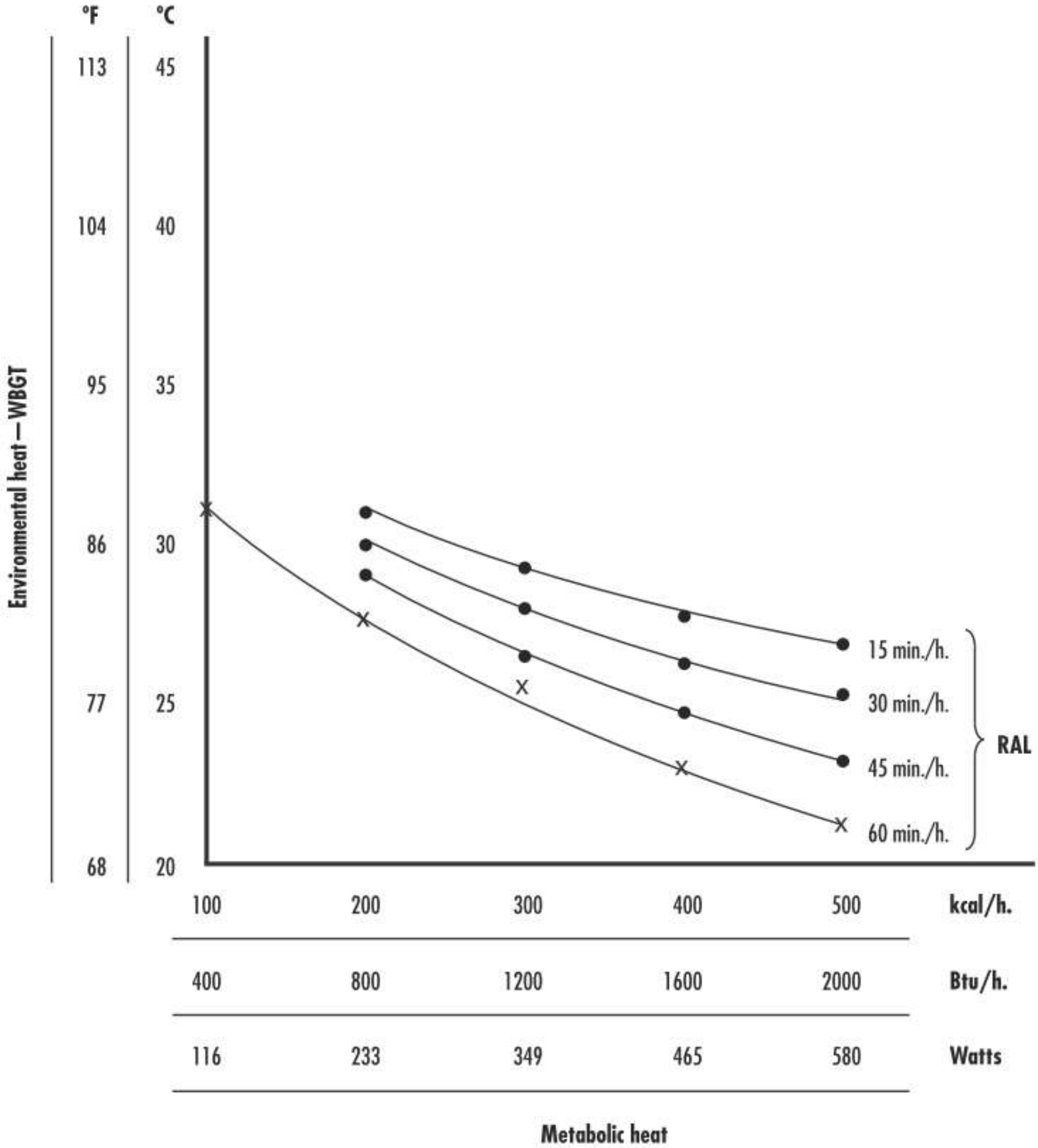

Figure 2.3 NIOSH recommended heat stress alert limits (RALs) for unacclimatized workers

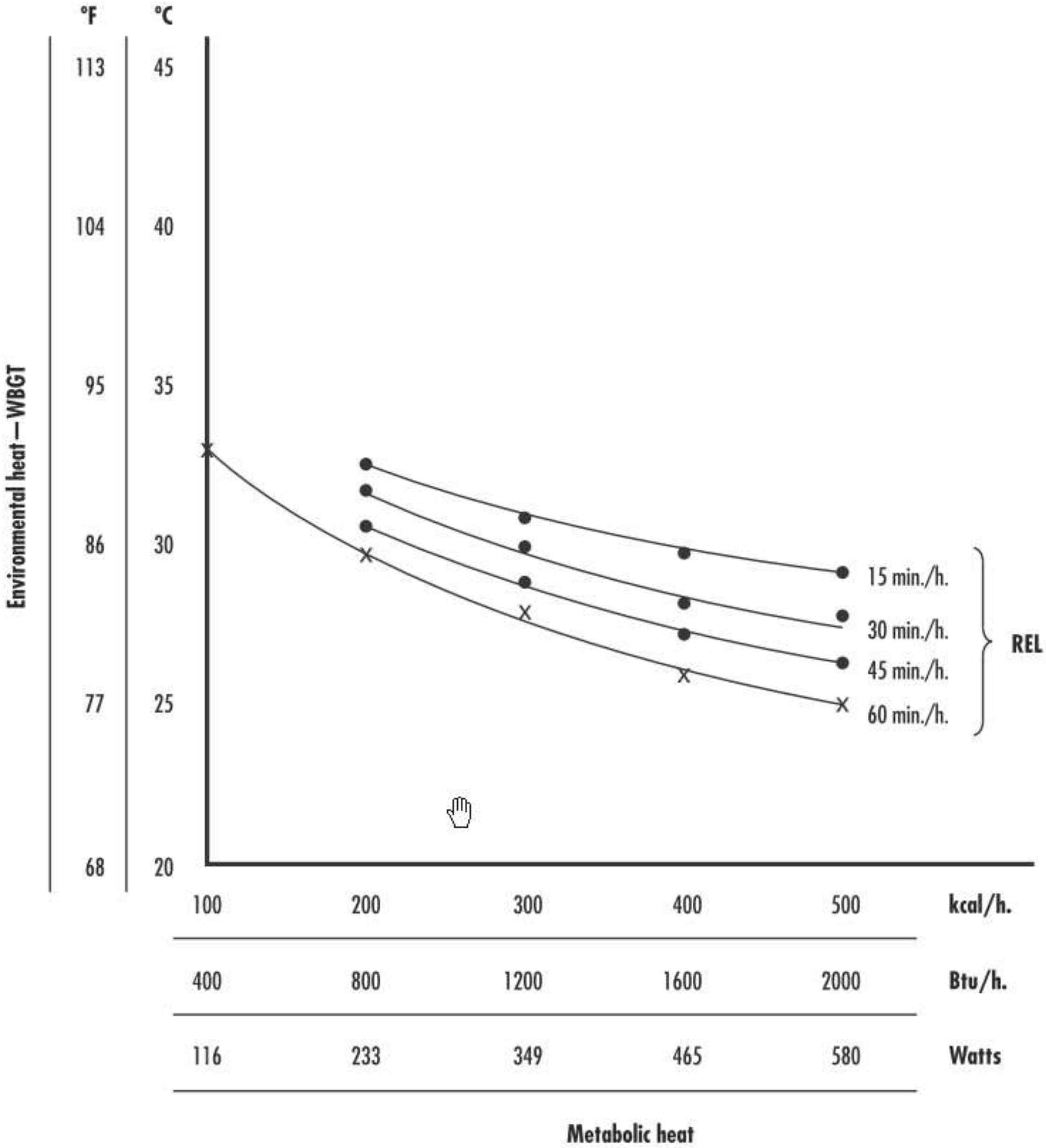

Figure 2.4 NIOSH recommended heat stress exposure limits (RELs) for acclimatized workers

As shown in Table 2.8, the estimation of metabolic heat loads is done in line with the ACGIH metabolic-work-rate guide

Table 2.8 Metabolic Work Rates

Work Category	**Metabolic Rate (Watts)**	**Examples**
Rest	115	Sitting
Light	180	Sitting, standing, light arm/hand work and occasional walking
Moderate	300	Normal walking, moderate lifting
Heavy	415	Heavy material handling, walking at a fast pace
Very Heavy	520	Pick and shovel work

Mandatory Rest Breaks

During workdays, employers are advised to initiate the recommended protective measures if RAL/REL is reached. Depending on heat loads, rest breaks, ranging between 15 to 45 minutes can be applied.

Cool Area for Rest Breaks

During work breaks, the criteria suggest that employees be granted access to rest areas that are either cool or air-conditioned.

Hydration

To sustain their hydration, employees must be granted access to clean, sufficient, and free water. Most importantly, workers must be educated on how to hydrate in line with the varying level of heat. For example, they must be made to understand the baseline of intake which is one cup of cool water per 15 to 20 minutes, as well as electrolytes.

Personal Protective Equipment

Workers suffering from heat must be provided with the necessary PPEs. This protective equipment significantly helps reduce heat stress. The PPEs range from water-cooled garments, air-cooled garments, to cooling vests.

B. Heat Acclimatization Plan

Employees likely to be exposed to high temperature working environments must be acclimatized for a period of one to two weeks gradually.

C. Exposure Monitoring

Employers are required to ensure employees are not exposed to working environments exceeding the RAL /REL requirements.

D. Medical Monitoring

Medical monitoring programs must be instituted to help deal with employees experiencing heat strain.

E. Emergency Medical Procedures

Emergency medical procedures must be established to help combat heat strain illness and symptoms

F. Hazard Notification

Warning signs must be provided in various languages and with clarity to increase employee awareness of their working environments.

G. Heat Alert Program

If heatwaves are forecasted, heat alert programs must be established to enhance employees' preparedness and awareness.

H. Worker Information and Training

Heat stress mitigation training must be regularly conducted to help supervisors and employees understand how to respond to the risk associated with heat illness. Therefore, employers must ensure that a well-drafted training program is implemented to bolster such training.

I. Heat-Related Surveillance and Recordkeeping

Data collected on deaths and injuries resulting from heat stress must be examined extensively along with other information such as physiological and environmental measurements. This helps employers understand how heat hazards can be neutralized. In the event of difficulty to eliminate the hazard, employers are advised to adhere to the NIOSH guidelines on NIOSH's "Checklist for controlling heat stress and heat strain"

2.10.2.2 ACGIH TLV for Heat Stress

A screening evaluation procedure by the ACGIH Threshold limit Value pays attention to the environmental factors incorporated in the WBGT index. The screening procedure works on the assumption of a typical work activity that gives room to recovery period and heat stress exposure. Heat stress has become a major challenge for employees exposed to hot working environments. The ACGIH describes heat stress, a physiological response of the body to heat stress. Often, heat stress causes fatigue, increased body temperature, and hydration. The human body is capable of maintaining its normal body temperature within a limited physiological range. The steady-state of the body is sustained by the body being able to regulate the core temperature. It is worth noting, however, that this is achievable when one is exposed to tolerable heat stress. Employees exposed to conditions depicted by intolerable heat stress, often incur overtaxed thermoregulatory defense of the body. By evaluating heat stress in occupational environments, the working population's heat strain is easily predicted hence enhancing the understanding of environmental parameters and internal heat loads.

2.10.3 International Standards

Occupational safety is conventionally considered an important factor in any industry as it not only bolsters productivity but also safeguards employees' health. Both national and international organizations in the United States have or adhere to standards, guidelines, and recommendations on increasing occupational safety. The guidelines or recommendations vary from official national and international standards to unofficial suggested procedures and practices. On the same note, the guidelines on occupational safety may also be unofficial recommendations proposed by research groups, institutions, or individual scholars within the health and safety fraternity. They all have a common goal of ensuring the safety of workers operating in high heat load conditions. (ACGIH, 2006).

A summary of U.S. Organizations and Agencies, International and Foreign Standards and Recommendations are shown in table 2.8

Table 2.9 Heat Stress Standards

	Organizations and Agencies	Standards
	AIHA	Employees along with their supervisors must be trained to conceptualize thermoregulation fundamentals. Workers must be educated on how to conduct exposure control. AIHA advocates for the adherence to then stipulated WBGT values and heat metabolic assumptions.
	MSHA	Employers must seek strategies to improve acclimatization Work/rest programs must be defined
	ACSM	Defines that Long distance athletes must have physical conditions that outdo most workers' physical fitness Races longer than 10 km should be avoided in the that temperatures surpass 28C Events in summer should only be conducted in early mornings or after 6 pm. fluids must be provided during such events
	Washington State Department of Labor and Industries	A safety program must be stipulated within the accident prevention strategy. Workers must be encouraged to regularly drink water.
International and Foreign	*ISO 7243*	Hot environments should be assessed based on the WBGT index
	ISO 7933	Internal core temperature and sweat rate must be predicted to assist in thermal stress evaluation.
	ISO 8996	Work practices, environmental metabolic rate and energetic cost an activity must be defined
	ISO 9886	measuring skin and body core temperature as well as heart must adhere to this ISO standard
	ISO 9920	thermal characteristics must align to this ISO standard
	WHO	Performance and productivity decrease as the ET or CET exceeds about 30°C (86°F). The WHO has recommended that for heat-unacclimatized individuals ET or CET values that exceed 30°C (86°F) for sedentary activities, 28°C (82.4°F) for moderate work, and 25.5°C (79.7°F) for hard work are unacceptable. For fully heat-acclimatized individuals, the recommended limits are increased about 2°C (3.5°F).
	Canada	Occupational temperature limits are guided by the ACGIH
	Japan	The ministry of health defines heat exposure guidelines. The Guidelines are dependent on acclimatization and protecting gear.

2.11 How the United States Army Deals with Heat Stress

According to the Armed Forces Health Surveillance Branch data, heat stroke and heat injury are proved to be the most severe illnesses incurred by US soldiers. The data notes that more than two hundred soldiers in 2014 were diagnosed with heatstroke. About 1200 other soldiers were found to be suffering from mild heat illnesses. The research shows much of duty time was dedicated to treating the patients hence loss of time. The nature of the arm operations ranges from carrying heavy equipment, wearing combat uniforms, and training outdoors (DeGroot et al., 2013). These types of activities tend to guarantee the exposure of soldiers to high-temperature working conditions. It is quite unrealistic to anticipate zero effects from the high-temperature working conditions on soldiers. Therefore, to mitigate the effects of heat stress on soldiers, the army actively engages in creating awareness through education and training to minimize the heat illness fatality (Alele et al., 2020). Before examining how the United States deals with heat stress, it is essential to conceptualize the heat illness spectrum. The spectrum ranges from heat cramps, heat injury, heat exhaustion, to dehydration and heatstroke. When soldiers undertake their activities in the heat, their muscles, and the demand for more blood flow. This is a necessary step for heat dissipation. When the need for more blood exceeds the pumping capability of the heart, one tends to experience heat exhaustion. Therefore, soldiers experience heat exhaustion due to cardiovascular events (Armed, 2018). This situation is worsened by dehydration. The severity of heat exhaustion and heat stress has made the US military adopt certain procedures to help the soldiers cope up with high-temperature working conditions. For instance, the military has safety procedures such as the black flag that help commanders define whether weather conditions are conducive for training or military act activities.

Comparing how the military deals with heat stress in comparison with the civilian, it is evident that the guidelines defining heat injury prevention in the military are way distinct from the civilian perspective. The US army reduces the heat stress risk by incorporating the use of large volumes of prophylactic water as well as limitations of physical activity. It is worth noting that these guidelines are based on wet bulb globe temperature (Armed, 2018). The military approach to heat stress or injury is based on two primary elements: physical activity control and monitoring, and prophylactic water consumption. For instance, studies show that during meals, soldiers adopt the liberal use of salt shakers during the start of acclimatization. The army ensures that water intake and physical activities are practiced in line with an index that pays attention to aspects such as temperature, humidity, wind, and wet bulb globe temperature (Alele et al., 2020). The prevention approach using the index is determined by a formula that involves temperature from a black globe, wet bulb, and shaded dry thermometers. The army prevents heat stress by encouraging water intake of 0.5 quarts every hour of light exercise with WBGT of 25.5°C (77.9°F). Higher workloads or high temperatures environments call for soldiers to take 2 quarts of water every hour. On the same note, the US military also adheres to guidelines regarding workloads. For instance, there is no limitation for workload classified as moderate when temperatures are 25.5°C (77.9°F) and a duration of 10 minutes. However, the temperatures, in this case, should not exceed 34.4°C (93.9°F).

According to the guidelines with the United States Navy, soldiers are required to drink water 6 ounces every 20 minutes, when performing moderate exercises in mild hot conditions. These guidelines have been drafted to help young soldiers adapt to operational activities. However, studies note that such recommendations cannot be applied to civilians. Civilians are advised to be more cautious when performing certain physical activities. In terms of activity, the United States army moderates its activities and the likelihood of heat strain by continuously following the heat index (Smalley et al., 2003). A value higher than 90 is considered hazardous, hence prolonged exercises are restricted. More caution is practiced on individuals with higher risk factors. A value at 105 on the index proves that a heat stroke is imminent. Therefore, the army often curtails any form of activity at this level. To help soldiers' self-identify risk factors, the army conducts regular educational campaigns (Armed, 2018). Apart from monitored fluid consumption and guided physical activities, the army also practices other heat stress prevention exercises. For instance, clothing.

The US pays attention to how army clothes are designed. Sweating is a central body thermoregulatory mechanism. Hence, the design of the army uniform pays attention to the fact that one's body parts respond differently when it comes to heat dissipation. As much as the hat may be appropriate in guarding against direct heat, the design of the hat must be adequately ventilated (Armed, 2018). With the upper part of the body being more active in discharging heat, the nature of fabrics used for clothing must be different. Fabric that allows sweat to move to the surface to evaporate should be more used in creating upper body clothing. When it comes to acclimation, the army opts to engage soldiers in activities gradually (Alele et al., 2020). This is an approach that studies effectively in helping soldiers enhance their heat regulation efficiency. Monitoring is also another approach that the US army employs to regularly check on individuals with high risk to heat stress. For example, one of the monitoring procedures adopted by the army is the weighing of soldiers before and after exposure to hot environments. These measures are essential in advising one on fluid intake.

Most importantly, the US army significantly prioritizes the need to have air conditioning especially for troops deployed to high-temperature areas. In closing, the US army employs well-trained medics that extensively understand the standard military guidelines. At the same time, the military has been adhering to recommendations from researchers on how to treat and respond to heat stress. For instance, soldiers exposed to extreme heat must be removed from the hot temperature condition and if heatstroke is detected, the medical response must be immediate (Alele et al., 2020). The US Army trains its service personnel on how to respond to cases of heat exhaustion and heat cramps while in the field. Some of the procedures practiced include taking oral fluids, misting, or sprinkling tepid water over the patient. In sum, the United States army employs clinicians that understand military guidelines regarding treating patients exposed to hot working environments. Additionally, these experts advise commanders on how to restrict physical activities.

2.11.1 Studies Conducted In the United States Army on Heat Stress

Numerous studies have been conducted in the United States Army regarding heat stress. The studies collectively focus on ways to reduce heat strain as well as the impact heat stress has had on soldiers. One of the studies is:

Heat Adaptation in Military Personnel: Mitigating Risk, Maximizing Performance. This study was conducted by Michael Stacey, Iain Parsons, and David Woods. The primary objective of the research was to understand how the military maximize their operations while dealing with risks from heat. The study acknowledges that the army often employs heat strain mitigation strategies that are reminiscent of civilian life. The scholars find that the military always has to undertake its activities such as reaching certain goals upon deployment as well as selecting special units under prolonged intense temperatures. Deployment to hot environments or performing high-intensity exercises tends to challenge the overall objective of protecting military personnel from heat strain (Parsons et al., 2019). While conducting their research, it is evident that acclimatization significantly reduces morbidity as well as influence the rate of mortality. Heat stress causes occupational, medical, and logistical difficulties within the military. These often call for risk stratification in the wake of heat strain.

Based on data collected during the research, this study aims to define how heat adaptation is important in helping carry out military operations in hot environments. Further, it focuses on defining effective solutions on optimizing paradigms of risk performance. Heat adaptation is boldly described as a major aspect within the military. Heat adaptation is perceived as a vital aspect of eliminating the risk presented by heat strain (Parsons et al., 2019). Within the military, heat adaptation was found by this report to serve two primary purposes. That is, combating heat stress and enhancing mental functioning and physical performance. To help soldiers acquire adaptations to heat, one is continuously exposed to artificial heat and heat stress.

In closing, the authors concluded that heat stress is a major hurdle to military operations. They concur that with climate change on the horizon, the military is likely to continue facing more advanced challenges to their operations. The study recommends that with the innovation in the horizon of military operations, heat stress mitigation strategies must be re-examined.

Heat strain during military training activities: The dilemma of balancing force protection and operational capability (Hut, Billing, et. al., 2016), focuses on heat strain experienced by soldiers during training. According to the study, military activities come along with two demands. That is, the need to undertake realistic operations with the intent of developing an operational ability while protecting the military personnel. The study looks into the risk associated with heat and heat strain to ascertain if limits to work duration help protect personnel and if they limit military operations. The study underlines how exposure to heat can significantly impact an unprepared individual. The study finds that military training is often conducted within well-structured guidelines to protect trainees from heat strain. The guidelines act as management tools that help define conducive limits to work or training periods. The work duration limits are determined by biophysical modeling of the core body's temperature elevation rate. In summary, the study provides evidence proving that force protection seems to be hindering many from being able to perform effectively in high temperatures environments. Lastly, the authors underline to determine effective physiological criteria, physiological mechanisms must be re-examined.

"Systematic review of gender differences in the epidemiology and risk factors of exertional heat illness and heat tolerance in the armed forces" was the objective of the Alele, Malau-Aduli, et al., (2020) study to describe heat illnesses epidemiology in women while comparing it to the male gender within the army. Also, the researchers focused on differences in heat tolerance and risk factors based on gender. The study concluded that men tend to experience an elevated level of heat stroke compared to women. Despite the scarcity of evidence, the study discovered that a higher portion of women in the army is more prone to heat illnesses due to their poor capability of heat tolerance. The scholars note that due to the limited evidence gathered during the study, the further must be conducted to help understand how gender relates to heat stress and heat intolerance.

Heat Illness, Active Component, U.S. Armed Forces, (Armed, 2018) is another study conducted within the US army to examine heat illnesses and stress. The study aims to shed more light on heat stroke cases within services men and women and recommends guidelines and procedures commanders and medical personnel units need to adopt. The study finds that the effectiveness of servicemen and women can be deteriorated if heat stress is not addressed effectively. For example, the researchers note that effectiveness can be deteriorated during training in arms specialties. The study concludes by underlining the troop deployments or training must be conducted in such a way that soldiers are well educated on preventive countermeasures and heat stress risks. Services must be able to define early signs and first response actions.

2.11.2 Non-Invasive Methods Used To Measure Temperature by the Army

The military is primarily known to rely on electronic devices to measure the core body temperature. The electronic thermometers as they easily measure core body temperature rectally, axillary, or orally. The military finds this noninvasive method effective as it enables monitoring of soldiers' temperatures around the clock with minimal personnel. The use of electronic thermometers to monitor temperature facilitates faster response to heatstroke/stress cases hence saving more lives of servicemen and women. However, it is worth noting that this method cannot be validated as a reliable means of continuously measuring temperature. This is because it provides values that tend not to reliably correlate to the core body temperature (Hunt et al., 2016). It is worth noting that the military employs the use of electronic devices as researchers have found it difficult to find a procedure that can reliably give continuous temperature measurements while remaining to be user friendly. In sum, despite the few challenges highlighted, scholars concur that the use of electronic devices helps monitor continuously the core body temperature (Radakovic et al., 2007). The limitation of using this noninvasive method is that it cannot be relied on full. Also, the devices can easily be damaged when placed. For example, during the application, studies show that this method showed extreme values due to malpositioning.

In conclusion, it is evident from the analysis that the military approach to heat stress is based on two primary elements: physical activity control and monitoring, and prophylactic water consumption. For instance, studies show that during meals, soldiers adopt the liberal use of salt shakers during the start of acclimatization. The army ensures that water intake and physical activities are practiced in line with an index that pays attention to aspects such as temperature, humidity, wind, and wet bulb globe temperature. The prevention approach using the index is determined by a formula that involves temperature from a black globe, wet bulb, and shaded dry thermometers. The army prevents heat stress by encouraging water intake of 0.5 quarts every hour of light exercise with WBGT of 25.5°C (77.9°F). Higher workloads or high temperatures environments call for soldiers to take 2 quarts of water every hour. On the same note, the US military also adheres to guidelines regarding workloads. One clearly notes that with the upper part of the body being more active in discharging heat, the nature of fabrics used for clothing must be different. Fabric that allows sweat to move to the surface to evaporate should be more used in creating upper body clothing. When it comes to acclimation, the army opts to engage soldiers in activities gradually. This is an approach that studies effectively in helping soldiers enhance their heat regulation efficiency. Monitoring is also another approach that the US army employs to regularly check on individuals with high risk to heat stress. For example, one of the monitoring procedures adopted by the army is the weighing of soldiers before and after exposure to hot environments. These measures are essential in advising one on fluid intake. Most importantly, the US army significantly prioritizes the need to have air conditioning especially for troops deployed to high-temperature areas. Based on the studies highlighted, scholars concur that hot environments or performing high-intensity exercises tend to challenge the overall objective of protecting military personnel from heat strain. While conducting their research, it is evident that acclimatization reduces morbidity and impacts the rate of mortality rate. Heat stress is a major hurdle to occupational, medical, and logistical activities within the military.

2.12 Climate Change

According to a report by an intergovernmental panel on Climate Change 5th assessment, emissions from the greenhouse effect have been increasing. The report notes that the emissions have been primarily fueled by human activities since the pre industrial era. There is a profound consensus within the scientific fraternity that increasing temperature is strongly contributing to the increasing trend of climate change (Pachauri et al., 2014). According to credible weather observations made, between 1983 to 2012 was the highest within the northern hemisphere where the global average temperature linear scope was 0.85°C (33.5°F). According to recent evidence, emissions from the greenhouse effect seem to be associated with anthropogenic activities. According to recent evidence, emissions from the greenhouse effect seem to be associated with anthropogenic activities. These effects are said to account for more than half of the increasing average global temperature between 1951 to 2010. The changing climate comes along with a range of consequences. Heat waves tend to be driven to last longer and are intense with frequent occurrence (Meehl and Tebaldi, 2004). This assumption has been proven by numerous studies that have adopted a variety of climate scenarios and models. In addition, the assumptions are being well supported by trends whereby projections in climate change showcase an increase in days characterized by heat waves. Conventionally, the severity of heat waves has been felt to the extent of causing deaths. In 2003, Europe recorded a total of 14,802 deaths. This led to an investigation where it was discovered that after the 2003 heat wave in Europe, more occurrences are more likely to be recorded on a daily basis in the future (Stott and Stone, 2004). Some researches note that the heat wave that occurred in 2010 in Russia and claimed 55,000 deaths is said to likely increase its probability of occurring by 2050. Its likelihood is expected to be between 5 to 10 times (Barriopedro et al., 2011). The US climate department notes that in most regions, the heat waves and summertime temperatures are expected to increase rapidly. This is expected to be experienced more in central and western US. In the event that the green emission continues to increase, the hottest temperatures of between 1950 to 1979 are likely to occur and even more severe between the years of 2035 and 2064.

2.12.1 Saudi Arabia Climate

Saudi Arabia's climate is classified under the BWh climate zone which is strongly impacted by arid conditions figure (2.5), this is according to the Köppen-Geiger climate (Peel et al., 2007). Countries experiencing such climate conditions are classified as deserts. Often, they experience low humidity, severe temperatures, scarce precipitation, and diurnal difference in temperature. Noteworthy, due to the massive land area of the Kingdom, the attributes of the climate of Dammam slightly differ, in experiencing high levels of humidity, owing to its geographical location and topographical characteristics. During summer, temperatures range between 45°C (113°F) and 54°C (129.2°F). During winter, they tend to remain above 0°C (32°F) see figure (2.6).

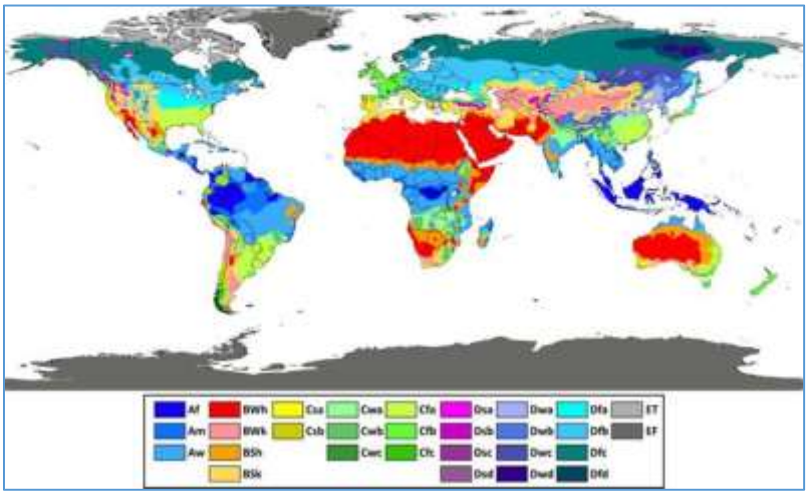

Figure 2.5 Köppen-Geiger Climate

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
00:01-01:00	13.3	14.9	18.4	22.6	28.4	31.4	33.6	32.4	29.2	25.1	20.9	15.0
01:01-02:00	12.9	14.4	17.7	22.1	27.7	30.9	33.1	31.8	28.5	24.6	20.7	14.5
02:01-03:00	12.3	13.9	17.2	21.8	27.1	30.3	32.7	31.4	28.0	24.0	20.2	14.2
03:01-04:00	12.1	13.5	16.7	21.1	26.3	29.7	32.2	31.1	27.4	23.5	19.8	13.7
04:01-05:00	11.8	13.2	16.2	20.6	25.9	29.4	31.5	30.6	27.1	22.8	19.6	13.5
05:01-06:00	11.6	12.8	16.0	20.7	25.6	29.1	31.4	30.1	26.8	22.4	19.2	13.2
06:01-07:00	11.4	12.5	15.4	20.7	26.1	29.4	31.3	29.9	26.4	22.3	18.7	12.9
07:01-08:00	11.3	12.6	16.5	22.5	28.8	31.8	33.3	32.1	28.5	23.3	19.0	13.1
08:01-09:00	12.4	14.5	19.1	25.4	31.7	34.8	36.3	35.2	31.5	25.9	20.6	14.5
09:01-10:00	14.7	17.4	22.4	28.6	34.8	37.8	39.2	38.5	34.8	29.4	22.9	17.1
10:01-11:00	16.9	20.0	24.9	30.6	37.0	40.1	41.5	40.8	37.5	32.0	24.9	19.4
11:01-12:00	18.6	21.9	26.5	32.3	38.7	41.4	42.5	42.3	39.4	33.8	26.3	21.3
12:01-13:00	19.8	23.0	27.5	33.4	39.5	42.1	43.4	43.4	40.7	35.4	27.1	22.6
13:01-14:00	20.4	24.0	28.4	34.2	39.7	42.5	43.8	43.8	41.2	36.3	27.7	23.5
14:01-15:00	20.9	24.6	28.6	34.5	39.9	42.6	43.6	44.1	41.3	36.5	27.8	23.8
15:01-16:00	20.9	24.4	28.6	34.2	39.6	42.4	43.5	43.7	40.5	36.2	27.6	23.5
16:01-17:00	20.5	23.9	28.0	33.0	38.7	41.5	42.8	42.5	39.5	35.0	26.8	22.6
17:01-18:00	19.4	22.7	27.0	31.4	37.3	40.4	41.8	41.1	38.1	33.4	25.5	21.1
18:01-19:00	17.5	20.4	24.8	29.7	35.5	38.7	40.4	39.6	35.9	31.3	24.2	19.5
19:01-20:00	16.4	19.0	23.1	27.7	33.6	36.6	38.3	37.6	33.9	29.8	23.5	18.4
20:01-21:00	15.6	17.7	21.7	26.4	32.1	34.8	36.8	36.0	32.6	28.6	22.9	17.5
21:01-22:00	15.0	17.1	20.9	25.4	30.9	33.8	35.7	34.9	31.5	27.7	22.3	16.8
22:01-23:00	14.4	16.5	20.3	24.6	30.2	32.6	34.9	34.1	30.7	26.8	21.8	16.1
23:01-24:00	13.8	15.6	19.4	23.8	29.2	31.9	34.1	33.0	29.8	25.8	21.2	15.5
Daily °C	15.6	17.9	21.9	27.0	32.7	35.7	37.4	36.7	33.4	28.8	23.0	17.6
Maximum °C	31.0	36.0	39.0	45.0	48.0	50.0	49.0	48.0	47.0	43.0	38.0	32.0
Minimum °C	2.0	5.0	6.0	13.0	19.0	24.0	22.0	24.0	20.0	16.0	8.0	5.0

Figure 2.6 Statistics for Dry Bulb Temperatures °C

2.13 Saudi Law of Occupational Safety and Health

In trying to promote occupational safety and health, the Saudi government has been making efforts through the Ministry of Labor and Social Development by providing new occupational guidelines. The guidelines provide employers with the framework on how to manage issues related to occupational safety and health. The kingdom's aims to improve employers' compliance to its National Strategic Program for Occupational Safety and Health.

The recently amended law on safety and health procedures in Saudi seeks to encourage more compliance from employers. The law requires employers to furnish their working environments with effective safety procedures and tools. This will help devoid likely causes of injuries, occupational diseases and accidents. As an employer, the new amended Saudi law stipulates that they must reduce the danger of equipment and tools used in sites. This will help prevent accident instances thus guaranteeing the safety of workers.

2.13.1 Three-Month Mid-Day Work Ban

During summer, the Saudi government has put in measures to guide employers on how to halt work between certain periods. The regulation however is limited by the fact that extreme temperatures can still be experienced outside the defined time. Some employers tend to disregard this law. For example, it was recently discovered that more than 2,000 violations of the law were recorded. These were instances where employers forced their employees to work outdoors within the times classified as extreme.

2.14 Wearable Physiological Monitors

Mitigating heat strain injuries were previously based on the assessment of the environmental heat conditions. Scholars note that this approach was in contrast to anticipated examinations of human body physiological responses upon exposure to heat stress in other terms, the previous assessments neglected the physiological reactions in terms of core temperature, heart rate, and sweating. Researchers have discovered that it is often difficult to offer protection to employees on an individual basis. This is because human bodies tend to respond independently to heat strain. Independence in response is attributed to inter and intra factors. The factors vary from sex and age to medication acclimatization. Hence, as much as numerous mitigation strategies have been advocated for, the protection of employees from heat stress injuries is expected to continue being a major challenge. Researchers that this level of independence in response to heat stress has negatively impacted the process or efforts of implementing a temperature guideline or standard dehydration formula to oversee all types of workers.

Technology innovation continues to take a key role in enabling the protection of employees from heat stress. For example, the technology in wearables has increased the ability to easily assess and monitor physiological indices. Despite the advantages of technology, tech experts admit that it lacks information utility systems. The system is essential for examining occupational heat stress. Therefore, scholars in the health and safety field insist that it is critical to creating more awareness in the identification of stress. They further urge that additional emphasis has to be placed on challenges facing the use and application of wearable technology. Working along these implementation procedures is perceived to play a vital role in combating occupational heat illnesses. It is worth noting that the information regarding the wearables can significantly help prevent and protect athletes from heat illnesses. Studies agree that wearable technology cannot be neglected as it helps enhance regulation adherence, increase productivity, and safeguard workers from occupational injuries.

2.14.1 Using Wearable Technology to Monitor Core Body Temperature

There is huge potential in wearable technology. The technology is said to come along with physiological sensor and signal integration. This is a helpful inaccurate prediction of the core body temperature. The launch of prediction equations to address challenges of noninvasive temperature marked the beginning of innovation in health and safety Givoni and Goldman (1972). It is based on the accuracy and effectiveness of the equations that many researchers have sought to study more on how to increase the complexity of the tool in terms of mathematical equations and integration of multiple sensors. Moreover, the applicability of the tool has been enhanced by the improved technology in smartphones. Smartphones bolster the computational power of the equations thus enabling accurate and prompt monitoring. Contemporary models are generally classified into two primary approaches. They are, those that operate upon physiological response integration and those that model based on mathematical algorithms of heat balance.

Models that primarily rely on equations of heat balance tend to need instrumentation for both metabolic heat generation and exchange. Some of the common themes among published models range from skin temperature, environmental humidity, and temperature and heart rate sensing (Fiala et al., 2012; Lee et al., 2018; Niedermann et al., 2014; Richmond et al., 2015; Xu et al., 2013). Meanwhile, more complex models that utilize multiple skin temperature sites, heat flux measurements, heart rate, and metabolic measurements improve the predictive ability of these models but limit their potential application in field settings.

In recent times, models that operate on a more integrated formula have been introduced to the industry. They tend to have much reliance on how physiological systems interact to minimize requirements for assumptions and sensors.

Chapter Three: Methods and Materials

3.1 Subject Selection

Twenty male electric utility employees volunteered to participate in this study. The participants were informed of the requirements of the trial and they had the opportunity to raise any questions or concerns before providing written consent to participate. Also, they were informed that participation in the study would be voluntary and that they could withdraw at any time.

Note: his procedure was approved by WVU Institutional Review Board (IRB# 1904534002) (see appendix A.1)

3.2 Subject Preparation

The participants were selected with no major health problems in the past (e.g., hypertension, diabetes, cardiovascular problem, or neurological disease) or symptoms of heat-related illness (e.g., confusion, drenching sweats, headache, fainting, nausea, shortness of breath, or cramps) and no history of smoking. Participants were divided into two groups. (1) Experimental Group: workers who have no work between noon and 3:00 p.m. (2) Control Group: workers who do not get this time protection.

The central objective of this research is to have a control group that resembles the experimental group in that the two can be perceived as the same. Achieving this level of similarity makes it easier to conclude that the difference in results is due to how experiential subjects were treated. In other terms, the similarity eliminates attributing the difference in results to the pre-existing distinction between the groups. To achieve similarity between the groups, the following factors were considered the following key features (task descriptions, subjects' acclimatization status, work load, clothing, age and body mass index) were considered to achieve similarity between groups:

3.2.1 Task Descriptions:

The participants' experience years in the same job range between 5 to 10 years and all of them were acclimatized to the following activities:

- Pulling of wires and cables in between buildings, poles, and towers.
- Straightening and replacing damaged poles
- digging holes for pole installation
- climbing utility poles
- Repairing or installing electrical systems.

3.2.2 Subjects' Acclimatization Status

All the participants were engaged in outdoor work and have acclimatized to work in a hot environment for more than one month.

3.2.3 Work Load

Metabolic heat loads can be approximated roughly according to the ACGIH metabolic-work-rate guide and recommended by the OSHA Technical Manual on heat stress. The study was limited to involve activities of heavy ($415 < M \leq 520\ W/m^2$) metabolic rate.

3.2.4 Clothing

The company clothing worn by the workers follow all applicable NFPA standards. Workers typically worked in two-layers of clothing, a fire-resistant, long-sleeve shirt with an undershirt. Workers pants and shirts were lightweight, breathable and not overly tight which allowed them to move around freely.

3.2.5 Age

The age of a participants was limited to be between 25 and 30 years.

3.2.6 Body Mass Index (BMI)

The 20 Participants classified as normal weight on the basis of their BMI ("normal weight": BMI = 18.5 – 24.9 kg/m^2).

3.3 Experimental Design

3.3.1 Subjects

A. Experimental Group: Ten (10) POLICY WORKERS. They have participated in both observations' periods (June 5-14 & June 15-24)

B. Control Group: Ten (10) NON-POLICY WORKERS. They have participated in both observations' periods (June 5-14 & June 15-24)

3.3.2 Variables

A. Independent variable:

1. Policy Period (2 levels: Before (June 5-14); After (June 15-24))
2. Worker Types (2 levels: POLICY WORKERS and NON-POLICY WORKERS)
3. Time of day (8 levels :((8-9); (9-10); (10-11); (11-12); (12-1); (1-2); (2-3); (3-4))

B. The dependent variable:

Mean core body temperature assessed by wearable noninvasive method.

3.3.3 Analysis

The data were analyzed using statistical analysis software IBM SPSS Statistics 27 and JMP Pro 14.0. For all hypothesis testing, the significance level was set at 0.05 ($\alpha = 0.05$). A three-way analysis of variance (ANOVA) was used to determine whether the group means from the two trials were distinct. The dependent variable was the body temperature. The independent variables were Worker Type, Policy Period, and Time of Day.

3.3.4 Objectives

A. To study the effect of worker types on mean core body temperature.
B. To study the effect of policy period on mean core body temperature.
C. To study the effect of time of day on mean core body temperature.
D. To study the effect of interaction between worker types and policy period on mean core body temperature.
E. To study the effect of interaction between worker types and time of the day on mean core body temperature.
F. To study the effect of interaction between policy period and time of the day on mean core body temperature.
G. To study the effect of interaction among worker types, policy period and time of day on mean core body temperature.

3.3.5 Null Hypothesis and Alternate Hypothesis

Null hypotheses: H_0

A. There is no significant effect of worker types on mean core body temperature.
B. There is no significant effect of policy period on mean core body temperature.
C. There is no significant effect of time of day on mean core body temperature.
D. There is no significant effect of interaction between worker types and policy period on mean core body temperature.
E. There is no significant effect of interaction between worker types and time of the day on mean core body temperature.
F. There is no significant effect of interaction between policy period and time of the day on mean core body temperature.
G. There is no significant effect of interaction among worker types, policy period and time of day on mean core body temperature.

3.4 Instruments

3.4.1 Core Temperature & Heart Rate Monitoring devices

Wearable Caretaker device were used to monitor the core body temperature and heart rate in real time on a continuous basis. The device consists of two parts (Figure 3.1). The first one called (VL-TEMP) to monitor the Core Temperature and another one called (CT4-KIT) to monitor Heart Rate.

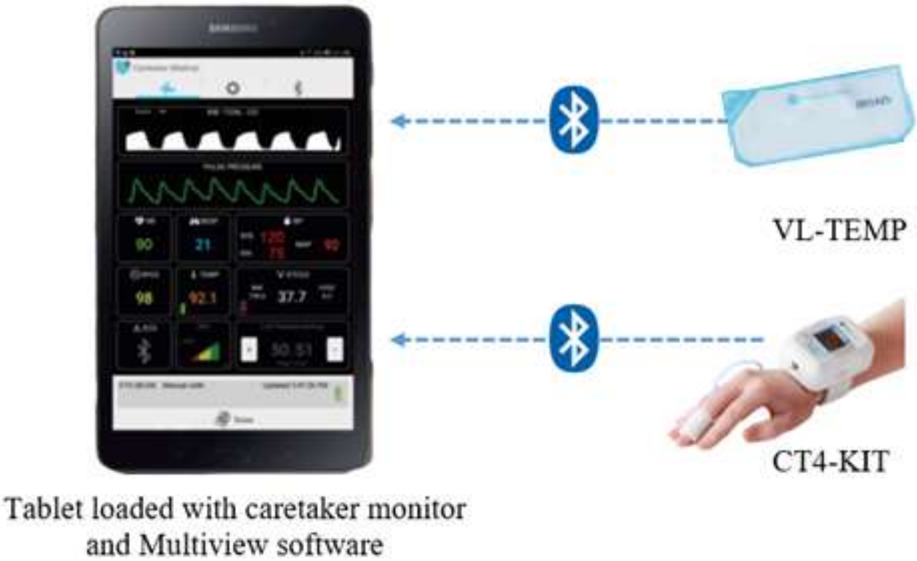

Figure 3.1 Core Temperature & Heart Rate Monitoring devices

<u>How it works:</u>

The VL TEMP is a wearable temperature monitor that is Bluetooth enabled. The tool is adequately embedded to help provide continuous data on temperature. The flexibility of the patch enables it to be attached to the underarm skin. The wearable thermometer is advocated by many as they adhere easily to the skin. This way they accurately and easily transmit temperature measurements to the Caretaker Monitor. Its Bluetooth compatibility boosts faster transfer. Reading of temperature is done in intervals of one minute. The CT4-KIT device physiologically senses temperature based on its three primary components. The components include a sensing pad, a pressure line, and a piezo-electric pressure. All components perform specific functions. The device is understood as a self-contained device that transmits data wirelessly. The signals transmitted represent the arterial pulse via Bluetooth.

3.4.2 Ambient Environment Monitoring

To measure the environmental parameters (Temperature, Humidity, Barometric Pressure, Solar Radiation, Wind Speed, Wind Direction) we will use Vantage Weather Stations (Vantage Vue + WeatherLink Live Bundle, USA) (Figure 3.2).

Vantage Pro2 console

Sensor Suite

Figure 3.2 Ambient Environment Monitoring device (Davis Instruments Model: 6820)

How it works:

The device comprises various sensors that detect humidity, solar radiation and anemometer, and temperature. The humidity and temperature sensors are placed in shields of passive radiations (Figure 3.3). This mounting enables it to reduce the intensity of solar radiation on readings. The wind speed is measured by the anemometer. To improve its effectiveness, it can be mounted adjacent to the sensor suite. The central processing of the sensor is carried in the transmitter suite. Its major function is to gather outside weather data.

Station's Components:

1. Wind Direction 2. Wind Speed

3. Rain Collector 4. Built-in Bubble Level

5. Radiation Shield 6. Temperature/Relative Humidity

7. Solar Radiation and UV Sensors 8. Wireless/Cabled

9. Weather Proof Housing 10. Solar Panel 11. Easy Installation

Figure 3.3 Station's Components

3.5 Test Protocol

Saudi's policy for occupational health and safety banned working under the direct sunlight from 12:00 to 03:00 p.m. between June 15 and September 15 that occurs every year. This study was performed outdoors and divided into two periods.

1. The Period before the mid-day break

This period took place for ten consecutive days, started on the 5th of June through 14th June 2020. Every day two participants (one from POLICY WORKERS and one from NON_POLICY WORKERS) have participated. Upon the arrival of the subjects to the site at 7:30 a.m., the experiment content was again described, and they were asked to sign an informed consent form and were asked to take rest. During this rest period, participants were asked to report their demographic information, including age, and personal health data, working experience and sleeping hours. The height, weight, resting heart rate, body mass index (BMI), and an oral temperature of the participants were measured. Body max index was calculated using the equation:

$$BMI = weight\ (kg) \div (height\ (m))^2 \text{.................(Equation 3.1)}$$

Participants were asked at 7:55 a.m. to attach the finger cuff and wrist unit and put on a patch (Continuous Temperature Sensor) for monitoring core body temperature. This patch was placed at right axillary of the participant.

At 8:00 a.m. the participants' core temperature and heart rate were monitored during their normal work routine using the VL-TEMP & CT4-KIT devices. Data of core temperature and heart rate of subjects were collected between 08:00 a.m. and 04:00 p.m. in their work shift when the work is in progress. Subjects performed their normal duties in the outdoor environment and the researcher did not interfere with or ask for any alteration to job activities. The maximum heart rate (HR_{max}) is the highest heart rate a person can safely achieve through exercise stress. Subjects' HR_{max} were estimated by using the age-predicted in the following equation:

$$HR_{max} = 220 - Age \text{................. (Equation 3.2)}$$

For the safety of participants, every participant was informed that he must stop when his HR reached 90% of the age-predicted HR_{max} or when he exhibited signs and symptoms of heat illness and he would be eliminated from the trial, then required to take-off clothing and rest in the shade. These precautions were in place to ensure that no participants would experience a heat-related injury during the trial. Every 15 minutes worker were asked to take water. At 10:20 a.m. and 02:00 p.m., there were rest periods of 10 min and 20 min respectively.

The environmental conditions (dry-bulb, wet-bulb, and black globe temperatures, RH, dew point, and Wind speed) were recorded at 10-min intervals throughout the shift (Vantage Vue + WeatherLink Live Bundle, USA). At the end of the shift, the data was downloaded in an excel sheet and 10 minutes averages were calculated.

2. The Period after the mid-day break

This period has started on the 15th of June through the 24th of June, 2020. The study was repeated for the same subjects and the same monitoring approach except that participants from POLICY WORKERS group were asked not to work under the direct sunlight from 12:00 to 03:00 p.m.

3.6 Questionnaire

A satisfaction survey was completed by each participant after the second trial to study were they satisfied with the device. Participants responded to each question using five-level Likert-type scales (e.g., 1 = strongly disagree, 5 = strongly agree) (see appendix C.1). These questions as below:

1. Is comfortable.
2. Is light.
3. Is simple to use.
4. Is suitable for continuous monitoring.
5. Does not detach from a user unless needed.
6. Does not affect job activities.

Chapter Four: Results and Analysis

4.1 Subjects' Personal Characteristics

Twenty male subjects were recruited for this study. The mean values of subjects' personal characteristics are presented in Table 4.1. (Detailed values for each participant are provided in appendix B.1).

Table 4.1: The Mean Values of Subjects' Personal Characteristics.

Characteristic	Mean	Standard Deviation	Maximum	Minimum
Age, Year	27	1.605	30	25
Weight, kg	72.4	2.854	76	67
Height, m	1.75	0.042	1.85	1.68
Body Mass Index, kg/m^2	23.8	1.034	24.9	21.8
Resting Heart Rate, bpm	71.4	9.752	86	59
Oral Temperature,°C	37.3	0.189	37.7	37.0

4.2 Daily Temperature

Table 4.2 presents the mean of daily temperature for the time from 8:00 a.m. – 4:00 p.m. for the policy period (Before and After). (Detailed values for climatic conditions are provided in appendix D).

Table 4.2 The Mean of Daily Temperature

`	Before	After
08:00	37.67	37.43
09:00	40.47	40.55
10:00	42.59	42.82
11:00	43.96	44.27
12:00	44.82	45.17
13:00	45.14	45.56
14:00	45.06	45.51
15:00	44.17	44.78
16:00	43.04	43.82

Table 4.3 Paired Samples t-Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	PostTemp - PreTemp	.18889	.44801	.14934	-.15548-	.53326	1.265	8	.242

A paired-samples t-test was conducted to compare daily temperature before and after applying the midday break policy (Table 4.3). There was no significant difference in the temperature for period before (M=43.3247, sd=2.71916) and period After (M=43.1358, sd=2.57503); t(8)= 1.265, p = 0.242. These results suggest that both periods have similar daily temperature.

4.3 Core Body Temperature

Data of body temperature were collected minute per minute between 08:00 a.m. and 04:00 p.m. then hourly averages were calculated. The groups mean body temperature values for both trials, with standard deviation, for each hour of the shift are given in Table 4.4

Note: "Raw data (roughly 60 pages) is available in .xls form by contacting the author."

Table4.4: The Groups Mean Body Temperature Values

Worker Type	Time	Mean	±	sd	Max	Min
NPW	8 to 9	37.657	±	0.203	38.012	37.283
	9 to 10	38.185	±	0.209	38.463	37.712
	10 to 11	38.492	±	0.264	38.791	37.859
	11 to 12	38.728	±	0.141	38.959	38.450
	12 to 1	38.725	±	0.146	38.959	38.400
	1 to 2	38.869	±	0.203	39.134	38.235
	2 to 3	38.837	±	0.225	39.247	38.243
	3 to 4	38.675	±	0.273	39.264	38.014
PW	8 to 9	37.671	±	0.210	38.084	37.311
	9 to 10	38.187	±	0.178	38.589	37.949
	10 to 11	38.625	±	0.109	38.807	38.416
	11 to 12	38.883	±	0.121	39.164	38.738
	12 to 1	38.706	±	0.165	38.909	38.238
	1 to 2	38.609	±	0.395	39.306	38.019
	2 to 3	38.480	±	0.519	39.194	37.788
	3 to 4	38.531	±	0.274	38.913	38.187

The mean body temperature values for all subjects (Non Policy Worker and Policy Worker) exceeded the allowable core temperature (i.e. 38.5°C; 101.3°F) suggested by the ACGIH to protect workers from having heat stress in both trials (Before and After).

Figure 4.1 shows in the policy period Before, the core temperature for both groups almost exceeded the allowable limit at the time period 10:00-11:00 a.m. and remained above the allowable limit.

In the policy period After, the mean body temperature for PW and NPW exceeded the allowable limit in the time period from 10:00-11:00 and 11:00-12:00 a.m. respectively. The mean body temperature in the policy period After for PW started decreasing in the time 12-1:00 p.m. While the mean body temperature for NPW remained above the allowable limit.

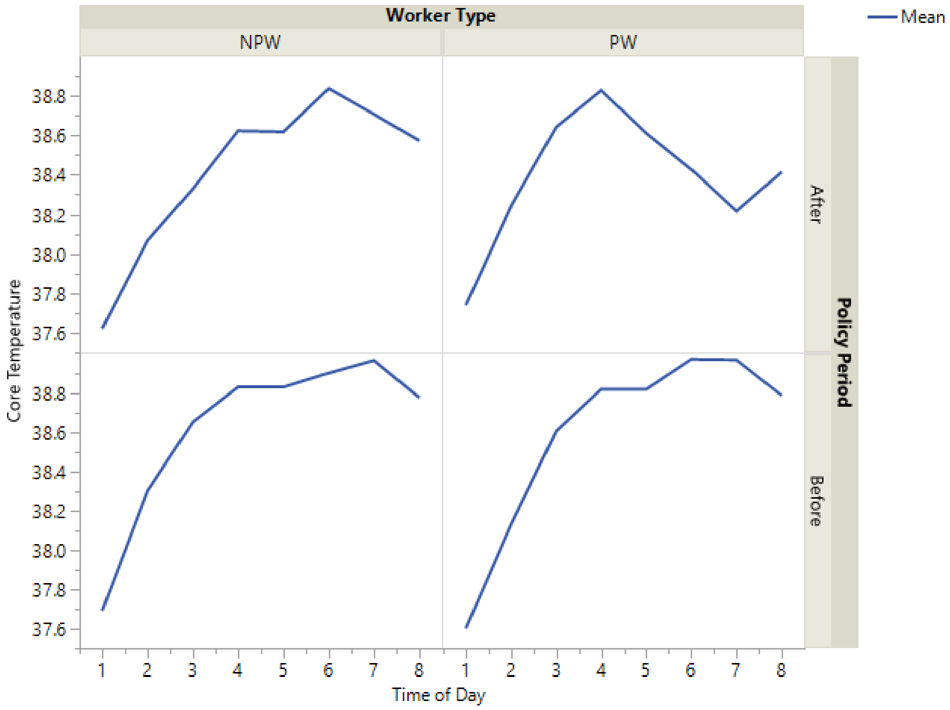

Figure 4.1 Groups' Mean Core Temperature for the Period Before and After

4.4 ANOVA

A three-way ANOVA was conducted to compare the main effects of Worker Type, Policy Period, and Time of Day and their interaction on the body temperature. Worker Type included two levels (Policy Worker, Non Policy Worker), Policy Period included two levels (Before, After), and Time of Day consisted of eight levels (8-9), (9-10), (10-11), (11-12), (12-1), (1-2), (2-3) and (3-4). The results of an ANOVA presented in Table 4.5 shows the test for the overall effects.

Table 4.5: Analysis of Variance

Source	Nparm	DF	Sum of Squares	F Ratio	p-value
Worker Type	1	1	0.078726	2.7091	0.1009
Policy Period	1	1	3.130239	107.715	<.0001
Worker Type*Policy Period	1	1	0.00004	0.0014	0.9703
Time of Day	7	7	42.885289	210.8187	<.0001
Worker Type*Time of Day	7	7	1.13462	5.5777	<.0001
Policy Period*Time of Day	7	7	1.987736	9.7715	<.0001
Worker Type*Policy Period*Time of Day	7	7	2.103178	10.339	<.0001

4.5 Testing of Hypothesis

A. There is no significant effect of worker type on mean core body temperature

The F value corresponding to the association between mean core body temperature and worker type was 2.7091 and its corresponding p value was 0.1009>0.05. Since the P value was greater than 0.05, we can conclude that, there is no significant effect of worker type on mean core body temperature. Hence, we can accept the null hypothesis and reject the alternate hypothesis.

B. There is no significant effect of policy period on mean core body temperature

The F value corresponding to the association between mean core body temperature and policy period was 107.715 and its corresponding p value was 0.0001<0.05. Since the P value was less than 0.05, we can conclude that, there is a significant effect of policy period on mean core body temperature. Hence, we can reject the null hypothesis and accept the alternate hypothesis.

C. There is no significant effect of time of day on mean core body temperature

The F value corresponding to the association between mean core body temperature and time of day was 210.8187 and its corresponding p value was 0.0001<0.05. Since the P value was less than 0.05, we can conclude that, there is a significant effect of time of day on mean core body temperature. Hence, we can reject the null hypothesis and accept the alternate hypothesis.

D. There is no significant effect of interaction between worker type and policy period on mean core body temperature

The F value corresponding to the association between mean core body temperature and interaction of worker type and policy period was 0.0014 and its corresponding p value was 0.9703>0.05. Since the P value was greater than 0.05, we can conclude that, there is no significant effect of interaction between worker type and policy period on mean core body temperature. Hence, we can accept the null hypothesis and reject the alternate hypothesis.

E. There is no significant effect of interaction between worker types and time of the day on mean core body temperature

The F value corresponding to the association between mean core body temperature and interaction of worker type and time of the day was 5.5777 and its corresponding p value was 0.0001<0.05. Since the P value was less than 0.05, we can conclude that, there is a significant effect of interaction between worker type and time of the day on mean core body temperature. Hence, we can reject the null hypothesis and accept the alternate hypothesis.

F. There is no significant effect of interaction between policy period and time of the day on mean core body temperature

The F value corresponding to the association between mean core body temperature and interaction of policy period and time of the day was 9.7715 and its corresponding p value was 0.0001<0.05. Since the P value was less than 0.05, we can conclude that, there is a significant effect of interaction between policy period and time of the day on mean core body temperature. Hence, we can reject the null hypothesis and accept the alternate hypothesis.

G. There is no significant effect of interaction among worker types, policy period and time of day on mean core body temperature.

The F value corresponding to the association between mean core body temperature and interaction of worker types, policy period and time of day was 10.339 and its corresponding p value was 0.0001<0.05. Since the P value was less than 0.05, we can conclude that, there is a significant effect of interaction among worker type, policy period and time of day on mean core body temperature. Hence, we can reject the null hypothesis and accept the alternate hypothesis.

4.5.1 Policy Period

An analysis, using the LS Mean Different Student's Test, to test differences between means of policy period was performed (Table 4.6). It shows there was a significant difference in core body temperature between the policy period before and after. This result suggests that there is a decrease in core temperature after applying the midday work ban policy.

Table 4.6: LS Mean Different Student's Test

Level	Grouping		Least Sq Mean
Before	A		38.60412
After		B	38.40631

Levels not connected by the same letter are significantly different.

Note:

Inasmuch as some of the findings are of statistical importance, it is uncertain if the significant differences are reliable outcomes or due to small sample size. The uncertainty of the findings is attributed to the small sample size. The following are the reasons that contributed to the limitation of the sample size:

1. Due to precautions that were taken to reduce the spread of COVID-19, the number of volunteers was limited

2. Culture issue regarding participating in experimental studies could have caused a reduction in volunteers. For example, people were not aware of the importance of participating in studies or they do not care.
3. Fear of discipline by employer or employee could have reduced volunteerism.
4. Inadequate public knowledge on the topic of the study. Most potential participants were reluctant to participate as they had little knowledge of the topic of the study and its significance.
5. The lack of public awareness of the ongoing study limited participation.
6. Voluntary response bias. While focusing on adapting to a consistent, simple, and effective system, volunteers were cautiously selected.

4.5.2 Time of Day

ANOVA followed by Tukey's Mean Separation Test was performed during the day to test the differences between its means (Table 4.7). The analysis shows the highest mean temperature was at the time level of 1 p.m. and 2 p.m. However, no significant difference was between the 11 a.m. and 3 p.m. period. On the other hand, the time level of 10 a.m. to 11 a.m. produced significant differences. 10 a.m. to 11 a.m. and 11 a.m. to 3 p.m. periods had significant differences despite the 10 a.m. to 11 a.m. period recording a least-square means above the allowable limit.

Table 4.7: Tukey's Pairwise Comparisons within Time of Day

Level	Grouping					Least Sq Mean
1 to 2	A					38.784
11 to 12	A					38.775
12 to 1	A	B				38.720
2 to 3	A	B				38.714
3 to 4		B	C			38.638
10 to 11			C			38.558
9 to 10				D		38.185
8 to 9					E	37.663

Levels not connected by the same letter are significantly different.

4.5.3 Worker Type X Time of Day

Tukey's Mean Separation Test was performed on the interaction between worker type and time of day to test differences between its means (Table 4.8). The analysis shows the highest mean temperature for the Non-Policy Worker was at the time level (1 p.m. to 2 p.m.). No significant difference was recorded between the Non-Policy Worker at the time level (11 a.m. to 3 p.m.) and Policy Worker at the time level (11 a.m. to 2 p.m.). In sum, the analysis provides sufficient evidence proving the lack of a significant difference between the Policy Worker and Non-Policy Worker at the time level (10 a.m. to 11 a.m.).

Table 4.8: Tukey's Pairwise Comparisons Interaction between Worker Type and Time of Day

Level	Grouping						Least Sq Mean
NPW,1 to 2	A						38.869
NPW,2 to 3	A	B					38.837
PW,11 to 12	A	B					38.824
NPW,11 to 12	A	B	C				38.727
NPW,12 to 1	A	B	C				38.725
PW,12 to 1	A	B	C				38.715
PW,1 to 2	A	B	C				38.699
NPW,3 to 4		B	C	D			38.675
PW,10 to 11			C	D			38.624
PW,3 to 4			C	D			38.601
PW,2 to 3			C	D			38.592
NPW,10 to 11				D			38.491
PW,9 to 10					E		38.186
NPW,9 to 10					E		38.184
PW,8 to 9						F	37.671
NPW,8 to 9						F	37.656

Levels not connected by the same letter are significantly different.

4.5.4 Policy Period X Time of Day

To test the differences between the interaction of Policy Period and Time of Day, Tukey's Mean Separation Test was performed (Table 4.9). The analysis shows the highest mean temperature was at the level (Before) with the time level (2 p.m. to 3 p.m.). No significant difference was captured before and After the policy period at the time level (11 a.m. to 12 p.m.). It is worth noting that the test conveys a significant difference before and After the policy period at the time level (12 p.m. to 3 p.m.). Further evidence shows the lack of a significant difference before and After the policy period at the time level (10 a.m. to 11 a.m.). In parallel, no significant difference was recorded before and After the policy period at the time level (11 a.m. to 12 p.m.). However, the 12 p.m. to 3 p.m. period portrayed an overwhelming difference before and After the policy period. Therefore, the test results suggest that as much as the midday work ban policy played a critical role in enhancing cooling mechanisms, it failed to adequately mitigate the risk of heat stress, especially during morning hours.

Table 4.9: Tukey's Pairwise Comparisons between Interaction of Policy Period and Time of Day

Level	Grouping						Least Sq. Mean
Before,2 to 3	A						38.967
Before,1 to 2	A						38.936
Before,12 to 1	A	B					38.826
Before,11 to 12	A	B					38.826
Before,3 to 4	A	B	C				38.782
After,11 to 12		B	C				38.725
After,1 to 2			C	D			38.632
Before,10 to 11			C	D			38.629
After,12 to 1			C	D			38.614
After,3 to 4				D			38.494
After,10 to 11				D			38.486
After,2 to 3				D			38.462
Before,9 to 10					E		38.217
After,9 to 10					E		38.154
After,8 to 9						F	37.680
Before,8 to 9						F	37.646

Levels not connected by the same letter are significantly different.

4.5.5 Worker Type X Policy Period X Time of Day

Tukey's Mean Separation Test was performed to test the differences between the interaction of Worker Type, Policy Period, and Time of Day (Table 4.10). The analysis shows the highest mean temperature for Policy Worker, policy period (Before), and the time of day (1 p.m. to 2 p.m.). No significant difference was captured in the following scenarios; Policy Worker, policy periods (before and after) at the time level (11 a.m. to 12 p.m.); Non-Policy Worker for before and after the policy period, at the time level (11 a.m. to 12 p.m.); Policy Worker for the periods (Before and after), in the time (10 a.m. to 11 p.m.) and Non-Policy Worker for the period before, in the time (10 a.m. to 11 p.m.) Moreover, there was no significant difference between the Policy Worker and Non-Policy Worker for before and after policy periods at the time level (12 p.m. to 1 p.m.). It is worth noting that a significant difference was recorded in the following scenarios; Non-Policy Worker in the policy period (after) at the time level (1 p.m. to 4 p.m.) and Policy Worker, Non-Policy Worker before and after policy period at the same time.

These results suggest three important issues: First, the policy helped in cooling body temperature from 1 p.m. to 4 p.m. Secondly, the results show that workers were more prone to heat stress at the time levels 10 a.m. and 12 p.m. Lastly, workers were more susceptible to heat intensity in the before the policy period..

Table4.10: Tukey's Pairwise Comparisons between Interaction among Worker Type, Policy Period and Time of Day

Level	Grouping											Least Sq. Mean
PW,Before,1 to 2	A											38.971
PW,Before,2 to 3	A											38.968
NPW,Before,2 to 3	A											38.966
NPW,Before,1 to 2	A	B										38.901
NPW,After,1 to 2	A	B	C									38.837
NPW,Before,12 to 1	A	B	C									38.831
NPW,Before,11 to 12	A	B	C									38.831
PW,After,11 to 12	A	B	C									38.828
PW,Before,11 to 12	A	B	C									38.820
PW,Before,12 to 1	A	B	C									38.820
PW,Before,3 to 4	A	B	C									38.788
NPW,Before,3 to 4	A	B	C									38.776
NPW,After,2 to 3	A	B	C	D								38.707
NPW,Before,10 to 11		B	C	D	E							38.653
PW,After,10 to 11		B	C	D	E							38.642
NPW,After,11 to 12		B	C	D	E							38.623
NPW,After,12 to 1		B	C	D	E	F						38.618
PW,After,12 to 1		B	C	D	E	F						38.610
PW,Before,10 to 11			C	D	E	F						38.606
NPW,After,3 to 4			C	D	E	F	G					38.573
PW,After,1 to 2				D	E	F	G	H				38.427
PW,After,3 to 4					E	F	G	H	I			38.415
NPW,After,10 to 11						F	G	H	I	J		38.330
NPW,Before,9 to 10							G	H	I	J		38.302
PW,After,9 to 10								H	I	J		38.241
PW,After,2 to 3								H	I	J		38.216
PW,Before,9 to 10									I	J		38.131
NPW,After,9 to 10										J		38.066
PW,After,8 to 9											K	37.739
NPW,Before,8 to 9											K	37.691
NPW,After,8 to 9											K	37.621
PW,Before,8 to 9											K	37.602

Levels not connected by the same letter are significantly different.

4.6 Subjective Responses

The questionnaire was completed by each participant after the second trial to study were they satisfied with the device. The results were as follows in table 4.11

Table 4.11: Descriptive Statistics for the Device Questionnaire

Questions		Strongly Agree	Agree	Undecided	Disagree	Strongly Disagree	Mean	sd	Rank
Is comfortable	N	3	13	4			3.95	0.604	4
	%	15	65	20					
Is light	N	12	8				4.60	0.502	2
	%	60	40						
Is simple to use	N	15	5				4.75	0.444	1
	%	75	25						
Is suitable for continuous monitoring	N	6	9	5			4.05	0.759	3
	%	30	45	25					
Does not detach from a user unless needed	N	3	8	7	2		3.60	0.882	6
	%	15	40	35	10				
Does not affect job activities	N	3	10	5	2		3.70	0.864	5
	%	15	50	25	10				
Weighted Mean							4.10		
Standard Deviation								0.676	

Table shows, from which we find that the highest average was awarded to the question 3 (is simple to use) with mean 4.75 and sd 0.444 followed by question 2: (Is light) with mean 4.60 and sd 0.502 followed by question 4: (Is suitable for continuous monitoring) with mean 4.05 and sd 0.759 followed by question 1: (Is comfortable) with mean 3.95 and sd 0.604 followed by question 6: (Does not affect job activities) with mean 3.70 and sd 0.864 followed by question 5: (Does not detach from a user unless needed) with mean 3.60 and sd 0.882. (Participant's Raw Responses are provided in appendix C.2).

Chapter Five: Discussion

The chapter primarily discusses experimental findings of the study along with its relationship to previous research. Research questions have been used to boost in-depth analysis of the findings. To offer more guidance to future researchers on the topic, the chapter highlights recommendations on future research as well as the limitations of investigation heat stress in Saudi Arabia. At the end, conclusions deduced from the study are discussed with an intent of underlining the major takeaways from the research findings.

5.1 Study Findings Related to Previous Research

Research Question 1: Does the ban on three-month midday outdoor work need to be extended to begin June 1st and end September 30th?

In most times of the year, Dammam City often experiences hot and humid climate. This climatic condition achieves its peak from mid of May to mid of October. Table 4.3 contains data on daily temperatures which provide sufficient evidence proving the lack of applicability of the midday break policy. The non-significant difference of the aftermath and pre-policy periods is clearly shown in the data (0.242>0.05). Therefore, the data adequately support a call to reevaluate the ban on midday outdoor working.

Based on the data presented in table 4.9, it is evident that the policy has had a non-significant impact on combating the effect of heat stress on workers. On the same note, the data also prove that workers tend to be exposed to intense heat in most hours of the day. Therefore, the policy needs to be amended in some way, perhaps to create a ban in a different time period, i.e., that the ban can begin on the 1st of June and end 30th of September. With scientists projecting that climatic conditions are likely to worsen in the future along with global warming on the horizon, the research data in Table 4.9 further supports the significance of extending the midday break.

Examining these experimental results, it is evident that workers were exposed to the highest heat intensity between 9 am and 12 pm, therefore, as much as the midday work ban helped in cooling, the policy banning work for certain workers did not mitigate the risk of heat stress, particularly in the morning hours. Hence, failing to increase the ban period may increase the probability of heatstroke among outdoor workers. This conclusion is underscored by Umar et al., in 2019. The current research proves that empirical data is not yet available to support the effectiveness of the administrative action in mitigating exposure to heat strain. Inadequate empirical data to support this safety measure by the Saudi administration has possibly resulted in a lack of awareness among supervisors, employers, and workers. With the policy in place, working sites have therefore ignored the need to adopt heat safety preventive and training programs beyond the mid-day break policy because they relied solely on the policy. With this level of unawareness on the horizon, it is important to extend the midday break coverage time as it will help enhance regulation's practicality and necessity, and experimentally investigate its effect. In fact, extending the policy coverage, will ease the implementation process of safety programs adopted by individual employers. Additionally, a wider ban period will possibly help safety training programs to be put into effect in a timely manner hence increasing the chances of creating adequate awareness on heat strain safety. Regardless, experimental validation is required.

Moreover, our findings along with the study "Heat Stress, a Hidden Cause of Accidents in Construction" done by Tariq Umar and Charles Egbu in 2020, conclude that most severe accidents in construction in Oman took place from 10 a.m. to 5 p.m. Heat stress is classified as the primary causative of these accidents. Evidence from the studies shows that despite the nationalization of the midday break policy, workers are yet to fully benefit. The policy was designed to cover the months of June, July, and August from 12:30 pm to 3:30 pm. However, researchers attribute the ineffectiveness of the policy to the fact that most of the summer period is not covered. In Oman, summer lasts from March to October.

The findings of our research correlate with the global WGBT values as well as studies such as "Workload assessment in building construction-related activities in India." by Maiti, (2008). That supports that the policy needs adjustments. For example, the increase in the WBGT values in the morning hours in our results is consistent with Maiti, R. (2008) findings, hence supporting the notion that heat intensity increases with a sunrise that marks its maximum at noon. As much as workers may be working in sheltered environments, our findings prove that the risk of heat stress is still high. These facts help underline the need for revising the policy on safety measures, followed by experimental investigation of policy effect.

Research Question 2: Does the midday break between 12:00 pm and 03:00 pm need to be extended by a few more hours?

Based on these findings, the midday break from noon to 3:00 pm has to be extended to cover hours that workers seem to be more vulnerable to heat stress. Our findings in the results chapter show participants' core body temperature exceeding the allowable limits outside hours covered by the policy. This evidence is enough to prod for policy change on working break hours. Despite our capability as humans of having a core temperature of 40°C (104°F), the ACGIH provides detailed guidelines on how the temperature can be sustained within the 38.5°C (101.3°F) limit. If the temperatures limits are exceeded, the ACGIH guides on how administrative controls can be applied. For instance, it provides a clear structure regarding hourly working limits aimed at ensuring safe levels of heat stress exposure.

Our findings along with the study "Assessment of Heat Stress Exposure among Construction Workers in the Hot Desert Climate of Saudi Arabia" done by Mohammed Al-Bouwarthan, Margaret M Quinn, David Kriebel, David H Wegman in 2019, supporting the need for extending the midday break. This is because the results clearly show that workers experienced core body temperature above the allowable limit between 9 am and 12 pm. The increase in solar radiation intensity is attributed to the fact that high humidity and radiant heat are experienced in the morning hours. The results provide evidence that the intensity of solar radiation increases with sunrise. Therefore, ensuring that the midday break is extended to start early and end before 3:00 pm should significantly help reduce heat strain (Al-Bouwarthan et al., 2019). As it stands, these results show that the current policy tends to lack the effectiveness in reducing heat risk exposure. To increase its capability in cupping the cumulative heat exposure, the midday break has to be extended to cover hours that workers experienced core temperature beyond the allowable limit.

The study finds those compliant to the midday work ban policy still susceptible to heat risk. This shows that to enhance the effectiveness of the ban, the hours need to be extended to cover hours of the day when workers are more vulnerable to heat strain. The results further show that the ineffectiveness of the work ban policy has coerced workers to practice self-pacing. That is, workers regulate their metabolic rate to protect themselves from heat stress (Yang, 2017). Therefore, ignoring the recommended amendments on the policy leaves workers to be survivors of difficult and taxing working conditions.

Research Question 3: How effective was the device used in the experiment?

Table 4.11 shows that the confidence to use the device in monitoring temperature continuously is positive (Agree), supporting the conclusion that workers had confidence in the device. The level of confidence is supported by the device readings of 4.10 on weighted average and 0.6763 standard deviation. The result is essential to production managers as they guide on how products can be redesigned to adhere to human factors, hence improving customer satisfaction.

5.2 Policy Alternatives

Apart from implementing further changes to the midday outdoor work ban policy, this study suggests:

1. The midday break is shifted to the early hours of the day as well as an extension of the policy to cover the entire summer season.
2. We also recommend to the ministry of labor to increase the number of workplace inspections. This will boost compliance with the midday break policy.
3. The production shifts need to be adjusted to have only two shifts rather than three. However, to successfully implement this, more precautions will have to be incorporated. For instance, workers' permission security, light among other factors.
4. Workplace safety can be enhanced by adopting engineering controls such as air conditioning. Air conditioning boosts cooling by increasing airflow and cool air.
5. Use PPE such as UV safety glasses, glasses with anti-fog coating, and heavy industrial clothing.

6. During the acclimatization periods returning or new workers have to be allowed to take more work breaks and be introduced to higher workloads gradually. Adhering to this procedure will significantly help improves an individual's heat tolerance.
7. Employers must also be advised and guided on how to effectively adjust work schedules and workloads to help employees maintain their core body temperature within the allowable limit. For instance,
   a. Days with a high heat index must reschedule all non-essential outdoor activities.
   b. Scheduling work outside the work ban policy hours.
   c. Shortening shifts and having numerous rest breaks in the shade or at least away from heat sources.
   d. International and ACGIH guidelines must be used when drafting rest and work cycles.
   e. Work must be rescheduled in the event of unavailability or inadequate control methods.
8. Workplaces vulnerable to heat stress need to prioritize slowing down manual activities. This can be achieved by employing mechanisms that help reduce manual handling.
9. During the summer season, shifts need to be shortened or heavy manual work is moved to morning hours.
10. Training and awareness programs have to be frequently carried out to increase the competency of employees and supervisors in evaluating heat stress symptoms and effective mitigation strategies.
11. Training programs must not only be made mandatory but also be presented in a way that workers and supervisors can easily understand.

12. Training programs should incorporate vital information such as health effects of heat exposure, and how to define the severity of symptoms.
13. Early detection capabilities need to be improved. This can be achieved through well-structured systems that ease the process of reporting and monitoring signs and symptoms.
14. Organizations and companies with working environments prone to heat stress must have effective emergency response plans and procedures. These procedures should frequently be practiced through drills to increase emergency response awareness among workers.
15. Companies must be coerced to make regular reports and records indicating cases of illnesses and injuries
16. Employees must involve mechanisms that help differentiate heat risk employees from others.
17. Employees must provide guidelines that help workers understand how to hydrate.
18. In sum, our study recommends that companies with working environments susceptible heat stress must avail guidelines on the following areas
    a. environmental monitoring
    b. nutrition
    c. sleeping/rest schedules
    d. hydration
    e. Fitness and heat acclimatization
    f. education programs
    g. working rate
    h. cooling apparel
    i. Policy on heat stress management.

5.3 Recommendations for Future Research

Scholars have to acknowledge that Saudi Arabia has a safety culture characterized by policies put in place with good intentions, but lacking experimental data for support one way or the other. It is vital for future studies to incorporate innovative ways on how employers and supervisors can adopt preventive interventions in their workplaces, and to back up in novation with science. The studies also need to focus on increasing awareness on heat stress mitigation strategies. Adopting this form of approach is likely to help organizations and employers understand the significance of having training programs on heat safety.

It is essential to pay attention to participants' physiologic responses in line with the heat exposures to be measured. This helps define the actual heat resilience. Most importantly, by understanding the physiological response, a study can easily understand workers' capability to improve productivity and withstand extreme heat. On the same note, engineering scholars need to focus their research on finding additional ways where engineering controls can be used to bolster heat risk mitigation and not simply policy, which is an administration, but necessarily less effective, control. Most importantly, scholars need to prioritize expanding their research to other sections of Saudi Arabia and elsewhere with hot and challenging climates to help create detailed conclusions and analysis. While conducting their study, researchers need to consider not only involving all the months of the year but also conducting their experiments within all the 24 hours of the day. This will significantly boost the ability to conduct an in-depth analysis of the topic.

To reliably assess the safety and health of employees, future studies must prioritize long- and short-term health implications of heat exposure. Most importantly, the studies must focus on chronic health difficulties. Monitoring environmental conditions continuously within the period of study must be exercised to help accurately reflect the heat trends of the day (Rowlinson, & Jia, 2015).

5.4 Strengths and Limitations

Strengths

The study incorporated physiological strain response as an evaluation tool hence enhancing the reliability of the findings. This approach significantly improved the accuracy especially when it came to evaluating heat stress exposures. The accuracy of the conclusions is attributed to the use of wearable temperature sensing devices in severe climates. The study avoided using the index of exposure as often, it involves using doses for empirical evidence and models

Limitations

Saudi Arabia often experiences hot climate from May to October. With the midday work ban taking effect June 15th to September 15th, means vital data on heat stress covering the other months was exempted from the study. This creates room for inaccurate conclusions. The study only focused on certain groups of the general population, the young and healthy. Those left out in the study prove that certain risk factors were not evaluated. Moreover, the study was limited to certain period of the midday break policy, to certain hours of the day and to certain areas of Saudi Arabia., hence, eliminating in-depth analysis.

5.5 Conclusion

Despite the vast implementation of the policy, other innovative administrative controls are necessary to help mitigate occupational heat stress. For instance, it is essential for the midday break to be shifted to the early hours of the day as well as an extension of the policy to cover the entire summer season. At the same time, production shifts need to be adjusted to cover only two shifts rather than three. Workplace safety can be enhanced by adopting engineering controls such as air conditioning. Employers must be advised on how to effectively adjust work schedules and workloads to help employees maintain their core body temperature within the allowable limit. Workplaces vulnerable to heat stress need to prioritize slowing down manual activities. This can be achieved by employing mechanisms that help reduce manual handling. During the acclimatization subjects must be allowed to take more work breaks and be introduced to higher workloads gradually.

Another policy alternative is ensuring training and awareness programs are frequently carried out to increase the competency of employees and supervisors when dealing with heat strain cases. Early detection capabilities need to be improved. This can be achieved through well-structured procedures that ease the process of reporting and monitoring signs and symptoms. As researchers, we advocate that working environments prone to heat stress be equipped with effective emergency response plans and procedures. Most importantly, the number of workplace inspections must be increased to improve policy compliance. Other policy alternative controls range from self-pacing, availing toilet facilities and sufficient water, proper clothing with new types of fabrics to help in cooling, evaporative fans, heat acclimatization, and air-conditioned resting areas.

Complying with the midday work ban policy (12:00–3:00 p.m.) was ineffective in reducing heat stress risk under the conditions and limitations of the design. Policymakers have to be alerted of this ineffectiveness and be advised on the best way forward regarding policy modifications. Intervention is key in guiding factors such as training courses, government plans, and creating awareness of heat stress. Apart from implementing further changes to the midday outdoor work ban, the Saudi administration must strongly consider implementing the noticeable missing preventive measures. This will help increase the effectiveness of the safety measure. Lastly, this study was a reasonable effort to test technology in real life in extreme heat conditions. Hopefully, this kind of research approach will be followed by other technology application efforts.

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Appendices

A.1 IRB

WestVirginiaUniversity.
OFFICE OF HUMAN RESEARCH PROTECTIONS
886 Chestnut Ridge Road Morgantown, WV 26506

Approval of Human Research Protocol

05/27/2020

To: Gary Winn

From: WVU Human Research Protection Program

Protocol Type: Expedited

Submission Type: Initial

Funding: N/A

Approval Date: 05/27/2020

Expiration Date: 05/26/2022

WVU Protocol #: 2004956140

Protocol Title: Assessment of Heat Stress for Outdoor Work Conditions in Saudi Arabia

The West Virginia University Institutional Review Board has reviewed and granted your request for approval of Expedited protocol 2004956140, in accordance with the Federal regulations 45 CFR 46, 21 CFR 50, and 21 CFR 56 (when applicable). Additional details concerning the review are below:

- Category 4. Collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subjects privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

The following documents were reviewed and approved for use as part of this submission. Only the documents listed below may be used in the research. Please access and print the files in the Notes & Attachments section of your approved protocol.

Protocol #: 2004956140 Phone: 304-293-7073
FWA: 00005078 Fax: 304-293-3098

- L o P.pdf
- survey.pdf
- Consent OMR-Jamal.pdf
- Arabic Ver.pdf
- citi Completion Report dr Winn.pdf
- Consent - add it is a student dissertation project.pdf

WVU IRB approval of protocol 2004956140 will expire on 05/26/2022.

If any study related activities are to continue beyond the expiration date, a renewal application should be submitted no later than four (4) weeks prior to the expiration date. It is your responsibility to submit your protocol for continuing review.

Once you begin your human subjects research, the following regulations apply:

1. Unanticipated, serious adverse events and/or side effect(s) encountered at WVU or an affiliate site that are related to the research must be reported to the WVU IRB within five (5) days using the Notify IRB action in WVU+kc.
2. Any Unanticipated Problem or UPIRTSO or other research related event resulting in new or increased risk of harm to study subjects, occurring at WVU or an affiliate site, must be reported to the WVU IRB within five (5) days using the Notify IRB action in WVU+kc.
3. Any modifications to the protocol or informed consent form must be reviewed and approved by the IRB prior to implementation. These modifications should be submitted as an amendment.
4. You may not use a modified informed consent form until it has been reviewed and approved by the WVU IRB. **Only consent forms with the WVU+kc watermark may be used to obtain informed consent from participants.**

The WVU Human Research Protection Program will be glad to provide assistance to you throughout the research process. Please feel free to contact us by phone at 304.293.7073 or by email at IRB@mail.wvu.edu.

Sincerely,

Lilo Ast

Lilo Ast
IRB Administrator

Protocol #: 2004956140
FWA: 00005078

Phone: 304-293-7073
Fax: 304-293-3098

Table B.1 The Individual Subject Characteristics

Worker Type	Age, Year	Weight, kg	Height, m	BMI, kg/m^2	Resting HR, bpm	Oral Temp.,°C
PW#1	29	71	1.69	24.9	84	37.3
PW#2	25	67	1.73	22.4	61	37.4
PW#3	28	73	1.73	24.4	62	37.4
PW#4	29	75	1.75	24.5	69	37.0
PW#5	25	74	1.8	22.8	59	37.5
PW#6	28	70	1.74	23.1	79	37.1
PW#7	25	75	1.74	24.8	79	37.4
PW#8	25	76	1.76	24.5	80	37.6
PW#9	28	69	1.77	22.0	66	37.2
PW#10	27	74	1.73	24.7	67	37.5
NPW#1	28	76	1.79	23.7	77	37.6
NPW#2	28	69	1.78	21.8	86	37.7
NPW#3	27	69	1.68	24.4	80	37.5
NPW#4	29	72	1.75	23.5	78	37.1
NPW#5	27	75	1.76	24.2	61	37.7
NPW#6	30	76	1.85	22.2	60	37.4
NPW#7	26	70	1.71	23.9	86	37.6
NPW#8	27	72	1.71	24.6	61	37.3
NPW#9	30	75	1.75	24.5	60	37.4
NPW#10	28	70	1.68	24.8	73	37.3
Mean	27.450	72.400	1.745	23.793	71.400	37.388
SD	1.605	2.854	0.042	1.034	9.752	0.189

C.1 Questionnaire Form

Questionnaire

Subject # ....

How effective was the device used in the experiment?

1. is comfortable

Strongly Disagree	Disagree	undecided	agree	Strongly Agree
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

2. is light

Strongly Disagree	Disagree	undecided	agree	Strongly Agree
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

3. is simple to use

Strongly Disagree	Disagree	undecided	agree	Strongly Agree
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

4. is suitable for continuous monitoring

Strongly Disagree	Disagree	undecided	agree	Strongly Agree
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

5. Does not detach from a user unless needed

Strongly Disagree	Disagree	undecided	agree	Strongly Agree
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

6. Does not affect job activities

Strongly Disagree	Disagree	undecided	agree	Strongly Agree
☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Table C.2 Participant's Raw Responses

	Q1	Q2	Q3	Q4	Q5	Q6
Questions	Is comfortable	Is light	Is simple to use	Is suitable for continuous monitoring	Does not detach from a user unless needed	Does not affect job activities
NPW1	4	5	4	5	3	4
NPW2	4	5	4	4	3	3
NPW3	4	5	4	4	4	5
NPW4	4	4	5	4	3	4
NPW5	3	5	5	5	5	5
NPW6	4	4	5	5	4	3
NPW7	4	5	5	5	4	4
NPW8	5	4	5	4	4	4
NPW9	4	5	5	4	5	5
NPW10	4	4	5	5	4	3
PW1	4	5	5	4	4	2
PW2	5	5	4	4	3	4
PW3	3	5	5	5	2	4
PW4	3	4	5	4	2	4
PW5	4	5	5	3	3	3
PW6	4	4	5	3	3	3
PW7	4	5	4	3	4	2
PW8	4	5	5	3	3	4
PW9	3	4	5	4	4	4
PW10	5	4	5	3	5	4

Table D.1 Daily Temperature, °C (Before)

	05/06/20	06/06/20	07/06/20	08/06/20	09/06/20	10/06/20	11/06/20	12/06/20	13/06/20	14/06/20
08:00:00	37.8	39.3	39.2	38.7	38.7	38.2	35.5	36.1	36.5	36.6
09:00:00	40.0	41.5	41.5	41.1	41.0	41.2	38.4	39.1	40.4	40.5
10:00:00	41.6	43.6	43.1	42.8	43.0	43.5	40.8	41.5	42.8	43.2
11:00:00	43.0	45.3	44.0	43.9	44.3	44.9	42.2	42.9	44.4	44.7
12:00:00	44.1	46.3	44.6	44.7	45.0	45.7	43.0	43.6	45.4	45.7
13:00:00	44.7	46.3	44.9	45.0	45.3	46.1	43.3	43.8	45.8	46.1
14:00:00	44.9	46.0	44.7	44.9	45.2	46.0	43.2	43.6	45.8	46.2
15:00:00	44.7	45.4	44.4	44.5	44.8	44.7	41.9	42.9	45.1	43.3
16:00:00	43.6	44.3	43.4	43.6	43.7	42.6	40.7	41.7	44.3	42.4

Table D.2 Daily Temperature, °C (After)

	15/06/20	16/06/20	17/06/20	18/06/20	19/06/20	20/06/20	21/06/20	22/06/20	23/06/20	24/06/20
08:00:00	36.7	32.8	38.6	37.2	39.1	39.0	37.2	38.8	37.3	37.6
09:00:00	40.0	35.9	41.2	40.2	41.7	42.2	40.4	42.2	40.2	41.5
10:00:00	42.2	38.0	43.6	42.6	44.1	44.1	42.7	44.5	42.2	44.2
11:00:00	43.7	39.4	45.3	44.3	45.8	45.3	44.0	45.8	43.5	45.7
12:00:00	44.6	40.2	46.4	45.4	46.8	45.9	44.8	46.5	44.4	46.7
13:00:00	44.9	40.6	47.0	46.0	47.2	46.0	45.2	46.8	44.9	47.1
14:00:00	44.9	40.4	47.0	46.1	47.0	45.7	45.1	46.8	44.9	47.2
15:00:00	44.2	39.2	46.8	45.9	46.4	45.0	44.7	46.8	44.6	44.3
16:00:00	43.3	38.5	45.5	44.9	45.0	43.7	43.9	46.0	43.8	43.4

Table D.3 Pressure, mmbar (Before)

	05/06/20	06/06/20	07/06/20	08/06/20	09/06/20	10/06/20	11/06/20	12/06/20	13/06/20	14/06/20
08:00:00	1005.5	1003.2	1006.4	1002.5	1002.6	1006.4	1004.8	1002.9	1002.7	1006.0
09:00:00	1005.6	1002.9	1006.0	1002.8	1003.1	1006.4	1004.9	1002.8	1003.2	1006.1
10:00:00	1004.8	1001.6	1004.5	1002.4	1003.0	1006.0	1004.6	1002.3	1002.7	1005.2
11:00:00	1004.4	1001.1	1004.0	1002.2	1002.7	1005.2	1003.9	1001.8	1002.4	1004.2
12:00:00	1004.6	1001.5	1004.3	1001.9	1003.2	1005.0	1003.9	1001.3	1001.9	1004.1
13:00:00	1003.4	1000.3	1003.7	1000.6	1001.9	1003.7	1002.6	999.8	1000.8	1003.4
14:00:00	1002.6	999.6	1002.9	999.5	1000.6	1003.4	1001.7	999.2	1000.6	1003.0
15:00:00	1001.7	1000.3	1001.8	999.7	1001.3	1002.9	1000.7	998.3	1000.2	1003.0
16:00:00	1001.8	1000.4	1001.7	1000.0	1001.7	1003.1	1001.2	999.1	1000.8	1003.6

Table D.4 Pressure, mmbar (After)

	15/06/20	16/06/20	17/06/20	18/06/20	19/06/20	20/06/20	21/06/20	22/06/20	23/06/20	24/06/20
08:00:00	1006.8	1004.8	1007.1	1007.2	1004.5	1004.6	1005.0	1004.1	1003.4	1002.9
09:00:00	1006.6	1005.1	1007.4	1007.2	1005.0	1005.2	1005.5	1004.3	1003.6	1003.0
10:00:00	1006.1	1004.6	1007.1	1007.0	1004.5	1005.1	1004.9	1004.0	1002.7	1002.6
11:00:00	1005.6	1004.2	1006.7	1006.9	1004.2	1005.1	1004.4	1003.6	1002.4	1002.3
12:00:00	1005.2	1004.2	1006.6	1006.6	1004.4	1004.5	1004.4	1003.6	1002.5	1001.9
13:00:00	1003.8	1003.8	1005.6	1005.5	1003.3	1004.5	1003.7	1003.0	1001.8	1001.1
14:00:00	1002.8	1003.1	1004.2	1003.9	1002.5	1003.7	1002.4	1001.7	1001.0	1000.1
15:00:00	1002.8	1002.5	1003.8	1004.3	1002.6	1002.9	1002.5	1002.0	1001.7	1000.6
16:00:00	1003.3	1002.2	1004.4	1004.3	1002.6	1003.0	1002.7	1001.9	1002.1	1000.7

Table D.5Relative Humidity, % (Before)

	05/06/20	06/06/20	07/06/20	08/06/20	09/06/20	10/06/20	11/06/20	12/06/20	13/06/20	14/06/20
08:00:00	37	31	29	18	14	20	15	14	37	25
09:00:00	25	22	24	12	9	19	9	10	27	21
10:00:00	18	16	21	10	8	16	7	7	22	18
11:00:00	14	14	20	10	8	15	6	7	19	16
12:00:00	12	12	17	9	8	15	4	7	19	15
13:00:00	12	12	15	9	8	14	4	8	19	15
14:00:00	11	12	13	10	8	14	5	8	20	16
15:00:00	15	11	8	13	8	9	6	13	17	17
16:00:00	16	11	8	14	8	10	7	16	18	19

Table D.6 Relative Humidity, % (After)

	15/06/20	16/06/20	17/06/20	18/06/20	19/06/20	20/06/20	21/06/20	22/06/20	23/06/20	24/06/20
08:00:00	35	44	56	34	43	33	38	30	17	19
09:00:00	30	36	50	29	37	28	28	25	12	18
10:00:00	27	33	44	26	32	25	23	22	14	18
11:00:00	27	30	39	25	30	25	21	21	13	17
12:00:00	28	29	34	23	28	26	20	19	13	16
13:00:00	29	28	31	23	28	27	19	16	13	16
14:00:00	30	28	28	23	28	28	21	14	11	16
15:00:00	33	27	28	25	30	31	18	9	11	15
16:00:00	35	28	29	28	33	32	19	8	14	17

Table D.7 Solar Radiation, w/m^2 (Before)

	05/06/20	06/06/20	07/06/20	08/06/20	09/06/20	10/06/20	11/06/20	12/06/20	13/06/20	14/06/20
08:00:00	500.2	503.7	506.4	502.9	499.3	499.3	494.8	499.3	502.0	504.6
09:00:00	679.1	683.5	687.1	680.0	675.5	665.7	665.7	674.6	678.2	680.0
10:00:00	823.3	827.7	833.0	821.5	817.9	808.1	817.9	816.1	820.6	820.6
11:00:00	920.3	926.5	932.7	918.5	914.0	911.4	913.1	913.1	918.5	917.6
12:00:00	963.9	971.9	977.2	962.1	956.8	954.1	955.9	956.8	964.8	962.1
13:00:00	952.3	959.4	964.8	950.5	945.2	942.5	944.3	946.1	955.0	951.4
14:00:00	883.8	889.1	896.2	882.9	878.4	877.5	878.4	881.1	889.1	884.7
15:00:00	767.2	763.6	777.9	767.2	745.8	761.0	762.7	766.3	772.5	769.0
16:00:00	605.2	603.4	616.8	607.0	600.8	602.5	605.2	609.6	614.1	612.3

Table D.8 Solar Radiation, w/m^2 (After)

	15/06/20	16/06/20	17/06/20	18/06/20	19/06/20	20/06/20	21/06/20	22/06/20	23/06/20	24/06/20
08:00:00	505.5	502.0	493.9	494.8	497.5	297.3	501.1	500.2	502.9	511.8
09:00:00	681.7	676.4	672.0	671.1	667.5	497.5	677.3	676.4	681.7	688.9
10:00:00	822.4	816.1	814.4	813.5	801.0	673.7	818.8	817.9	828.6	829.5
11:00:00	919.4	912.3	910.5	909.6	639.9	815.2	914.9	868.6	929.2	924.7
12:00:00	965.6	958.5	954.1	953.2	902.5	884.7	958.5	906.9	971.9	967.4
13:00:00	958.5	949.6	941.6	940.7	890.9	901.6	946.1	891.8	960.3	955.9
14:00:00	891.8	885.6	874.0	874.0	827.7	894.5	878.4	828.6	894.5	889.1
15:00:00	771.6	774.3	756.5	759.2	716.5	825.9	758.3	716.5	780.5	776.1
16:00:00	614.1	618.6	597.2	599.9	566.0	716.5	600.8	575.8	619.4	616.8

Table D.9 Wind Speed, m/s (Before)

	05/06/20	06/06/20	07/06/20	08/06/20	09/06/20	10/06/20	11/06/20	12/06/20	13/06/20	14/06/20
08:00:00	1.5	1.4	3.2	3.0	4.1	5.6	3.4	3.7	3.0	5.2
09:00:00	2.4	2.6	4.5	3.5	3.6	5.9	3.5	4.3	3.8	5.6
10:00:00	2.2	3.5	4.8	4.5	4.0	6.4	3.5	4.9	3.6	5.3
11:00:00	2.2	3.8	4.7	4.5	4.4	6.3	3.2	5.5	2.8	4.7
12:00:00	2.6	4.8	4.8	4.3	4.3	6.1	3.2	5.6	2.5	4.5
13:00:00	2.8	5.7	5.1	4.1	4.2	6.2	3.5	5.4	2.8	5.0
14:00:00	2.9	6.3	5.4	4.4	4.4	6.4	3.7	5.1	3.3	5.5
15:00:00	2.8	3.9	5.2	4.9	6.7	6.3	3.8	4.6	3.6	5.9
16:00:00	3.0	4.6	5.1	5.0	6.7	6.9	2.8	4.0	3.9	6.1

Table D.10 Wind Speed, m/s (After)

	15/06/20	16/06/20	17/06/20	18/06/20	19/06/20	20/06/20	21/06/20	22/06/20	23/06/20	24/06/20
08:00:00	6.8	5.0	1.8	3.1	1.4	2.0	1.8	0.8	4.3	3.4
09:00:00	7.1	5.4	0.8	3.5	1.2	2.1	3.0	1.1	5.1	4.3
10:00:00	7.0	6.4	0.5	3.3	1.7	2.3	3.8	1.8	4.9	5.7
11:00:00	6.9	7.6	0.7	3.3	2.2	2.0	3.2	2.4	5.2	5.7
12:00:00	6.5	8.2	1.3	3.4	1.9	0.5	2.8	3.0	5.5	5.6
13:00:00	6.7	8.8	2.0	3.4	1.9	1.5	2.6	3.4	5.9	5.6
14:00:00	7.0	9.2	2.2	3.2	2.2	1.7	2.7	3.7	6.4	5.6
15:00:00	7.2	9.1	1.3	0.5	0.6	1.9	4.0	3.5	6.9	6.5
16:00:00	7.0	8.5	1.2	0.5	0.6	2.9	4.1	3.7	6.8	6.4

[ends]